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BRITISH WELDING JOURNAL

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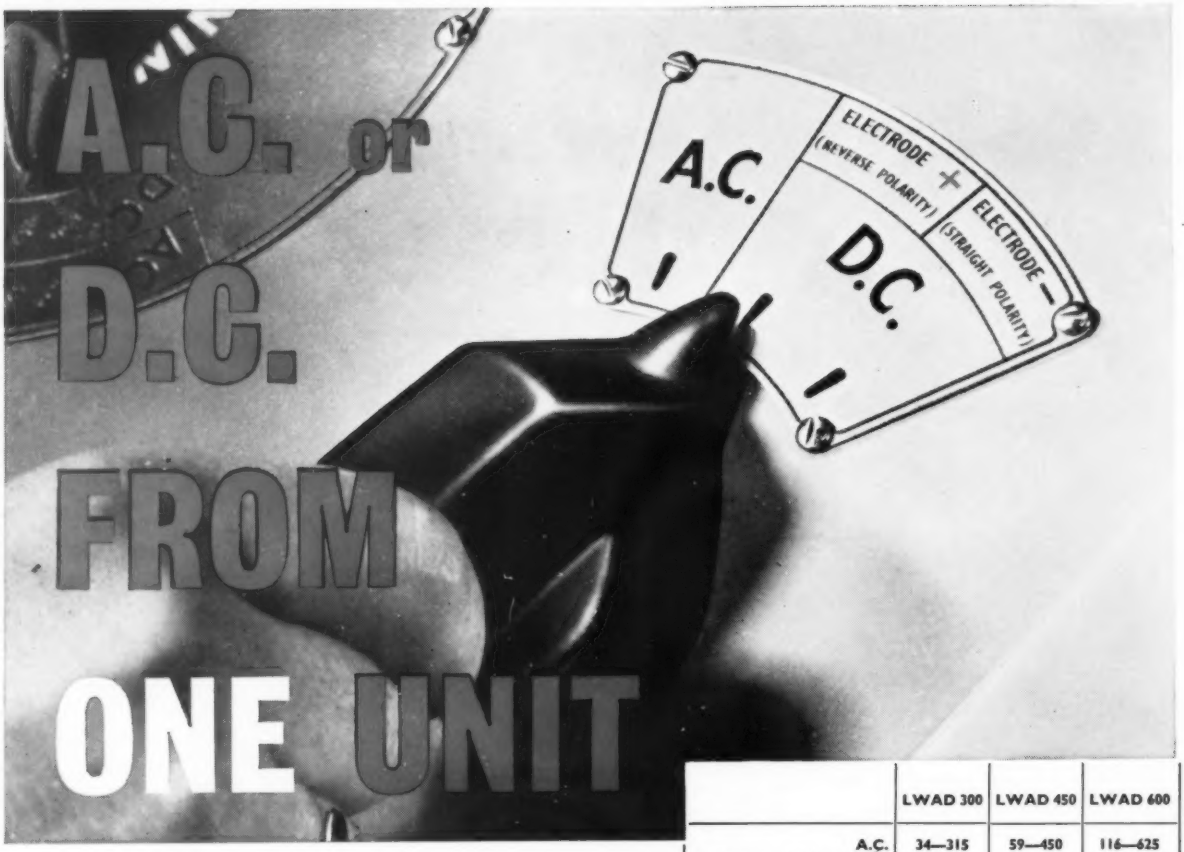

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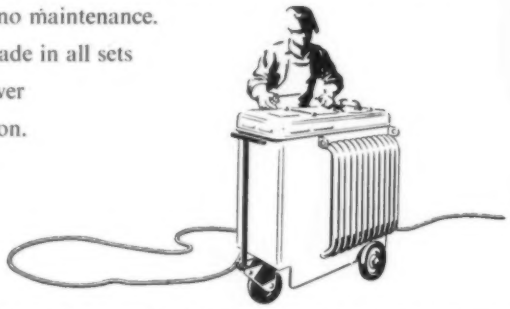

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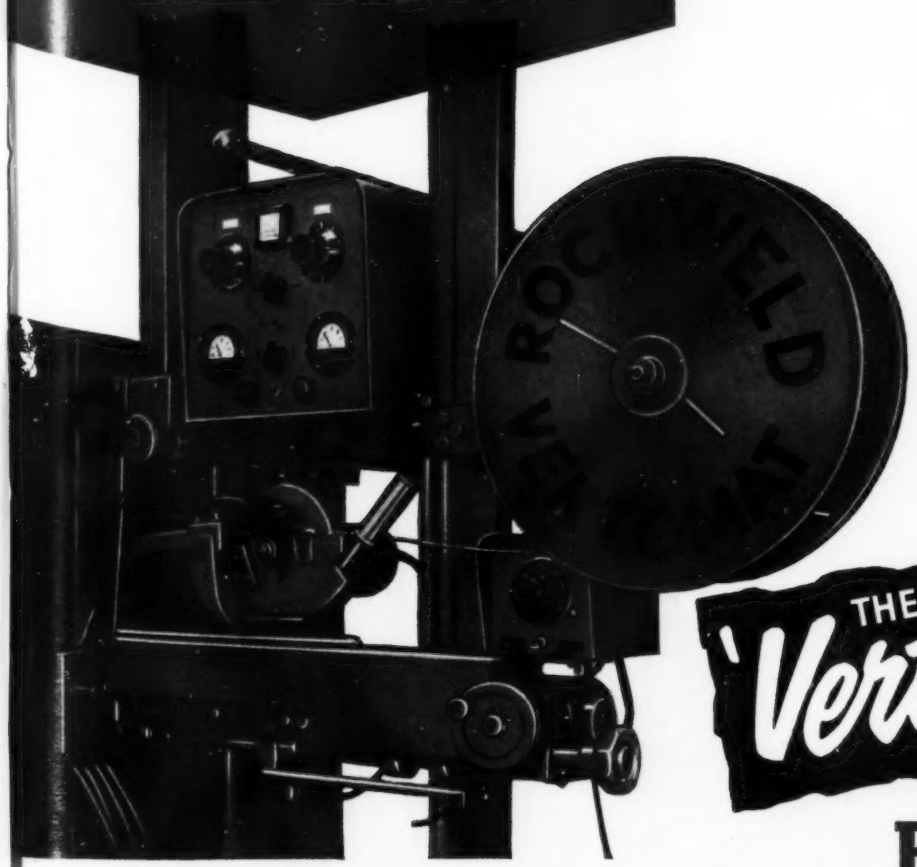

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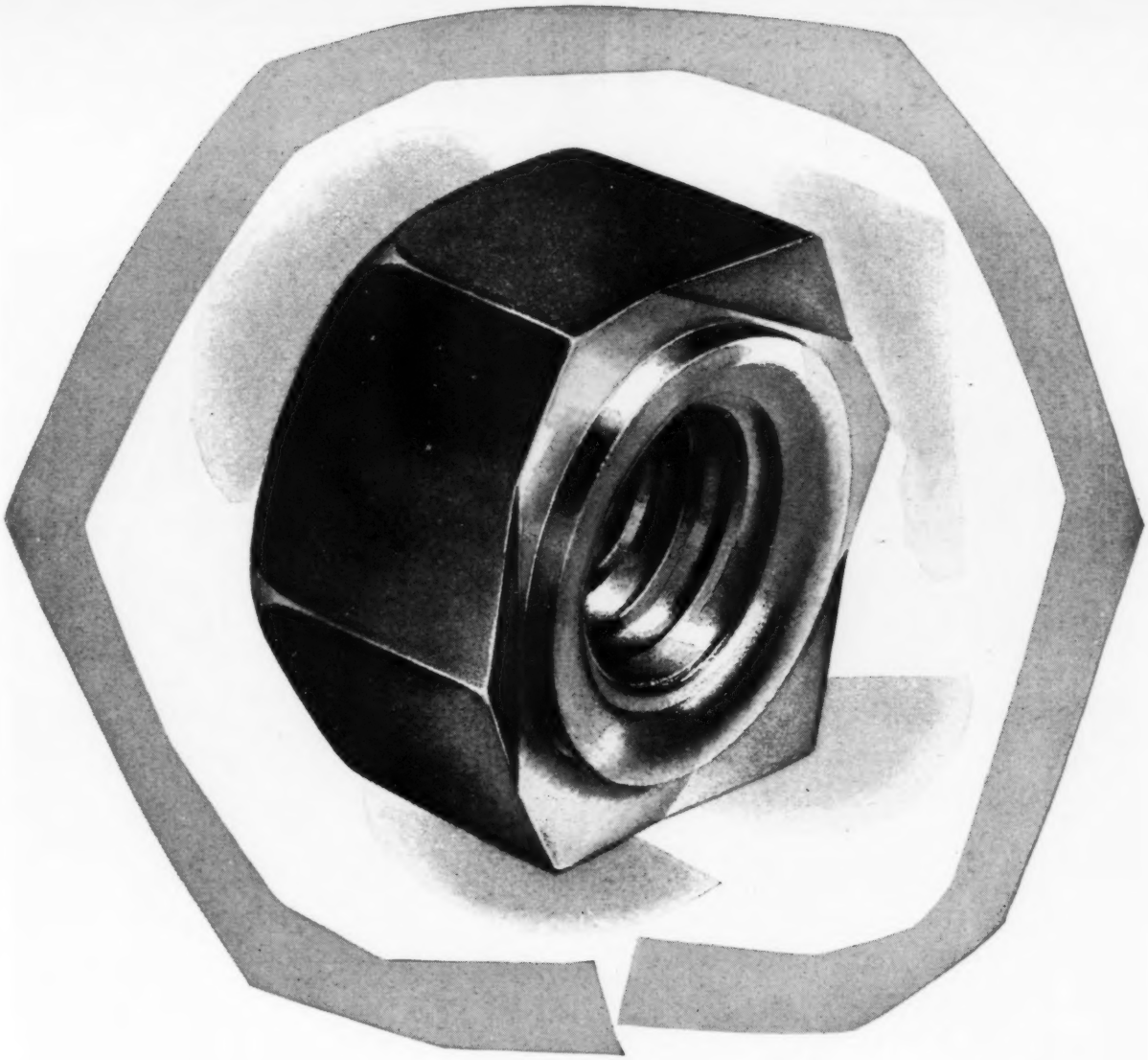

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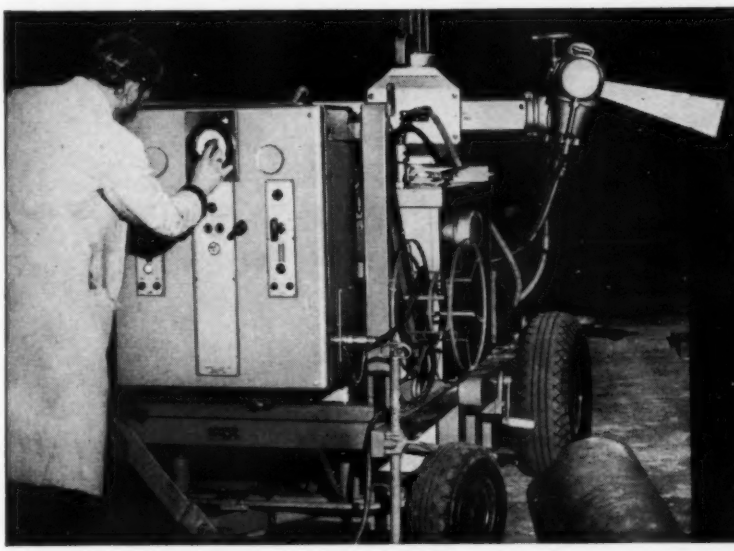

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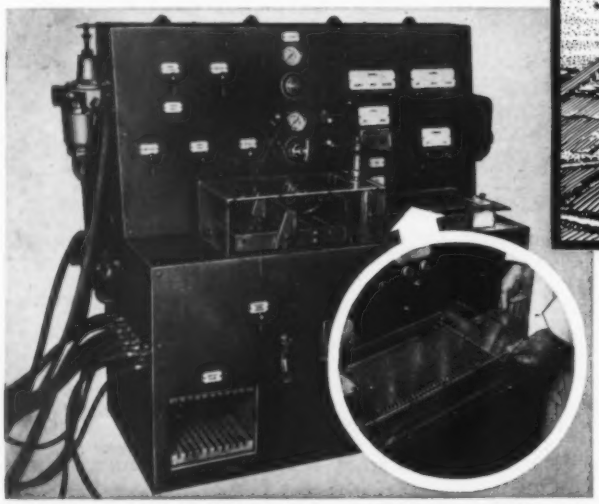

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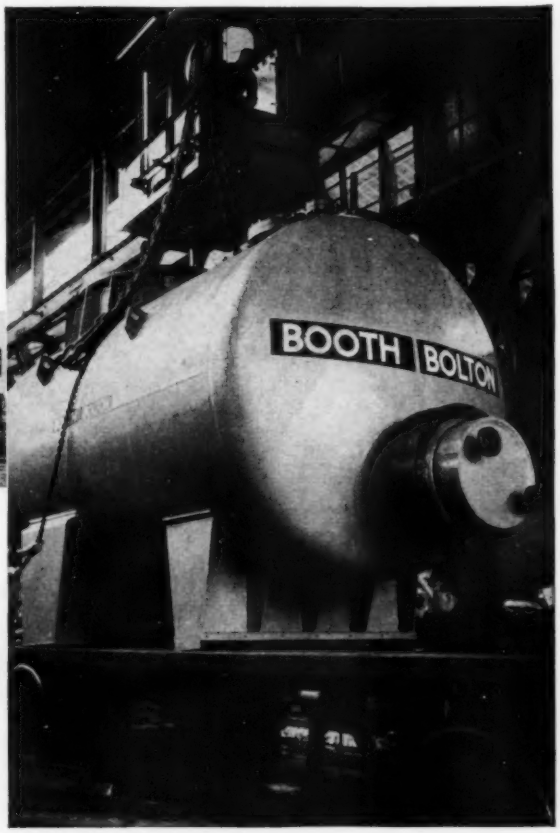

Right: Mild Steel Pressure Vessel for I.C.I.
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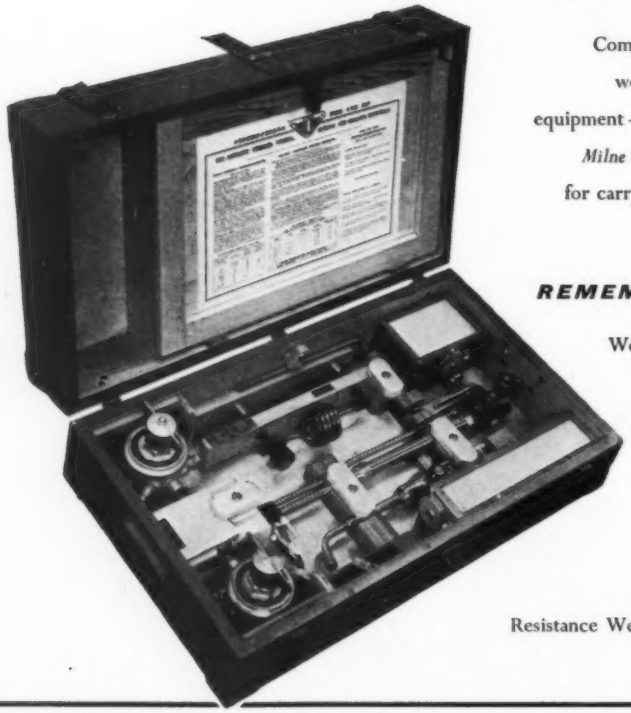

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BK 24	1200	140	—
BK 24A	1200	140	Integral
BK 24B	1200	140	Clamp on
BK 34	2400	355	—
BK 34A	2400	355	Integral
BK 34B	2400	355	Clamp on
BK 42	600	56	—
BK 42A	600	56	Integral
BK 42B	600	56	Clamp on
BK 66	300	22·4	—

* Ratings are for welder control service, with two valves in inverse parallel at any voltage from 250-600v. r.m.s.

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Type	Maximum peak voltage (Kilo volts)	Maximum average current at peak voltage (Amps.)
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BK 46	2·1	150
BK 56 †	20·1	150

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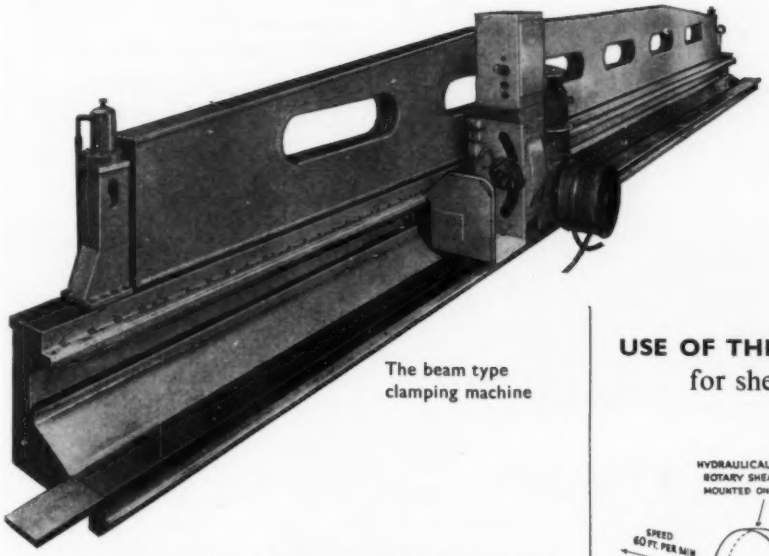

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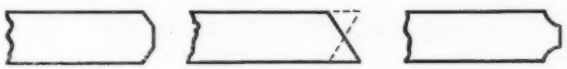

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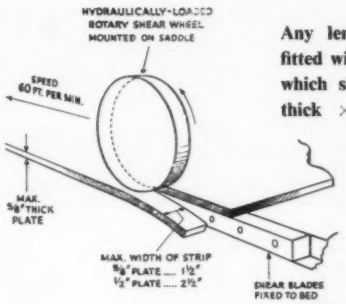
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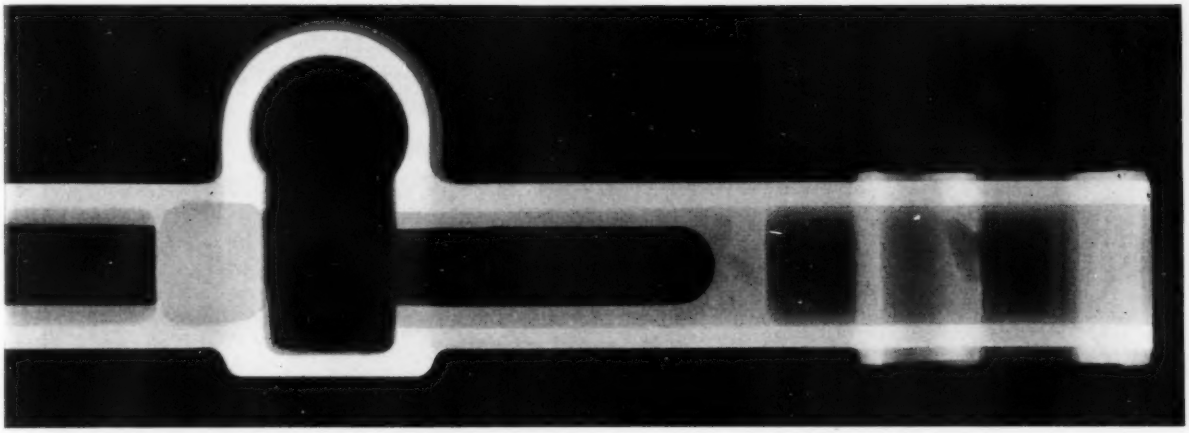

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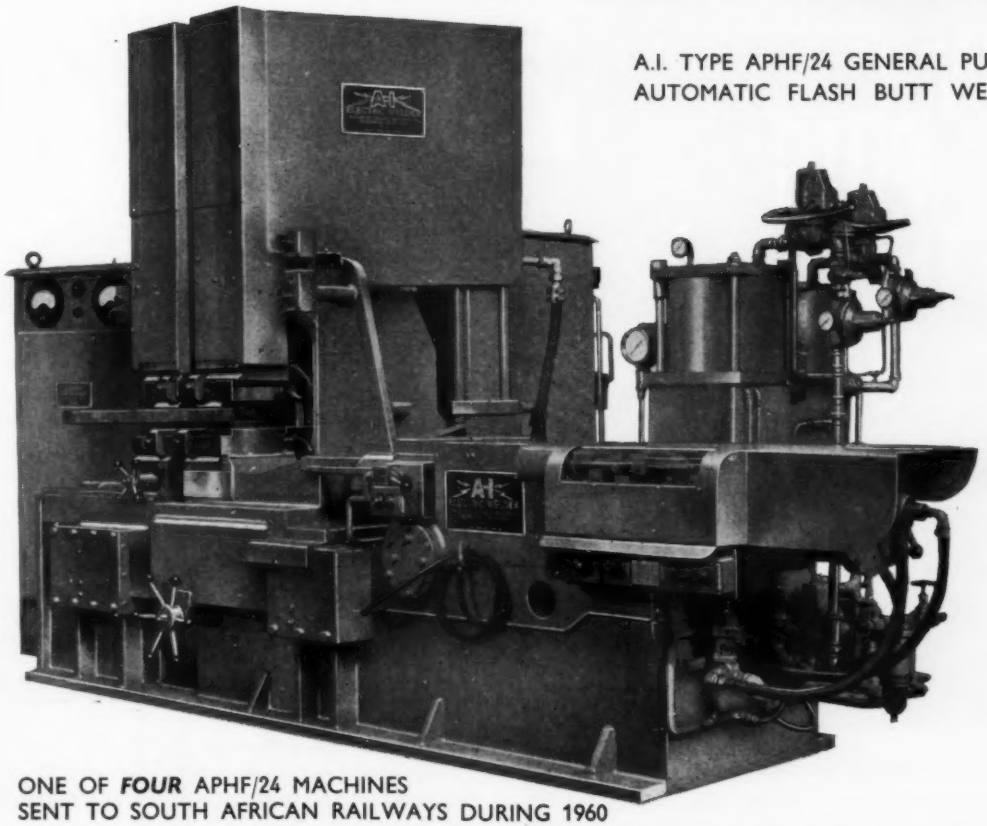

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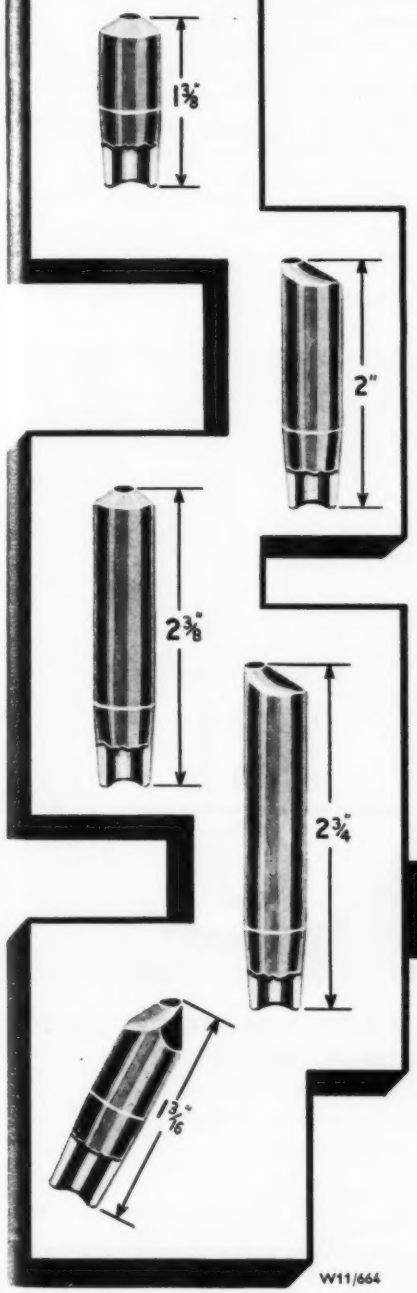

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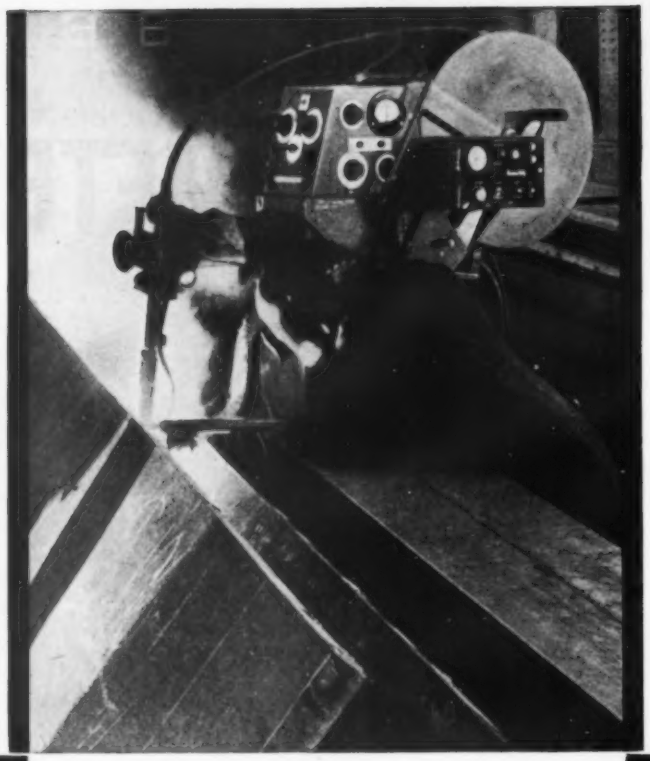

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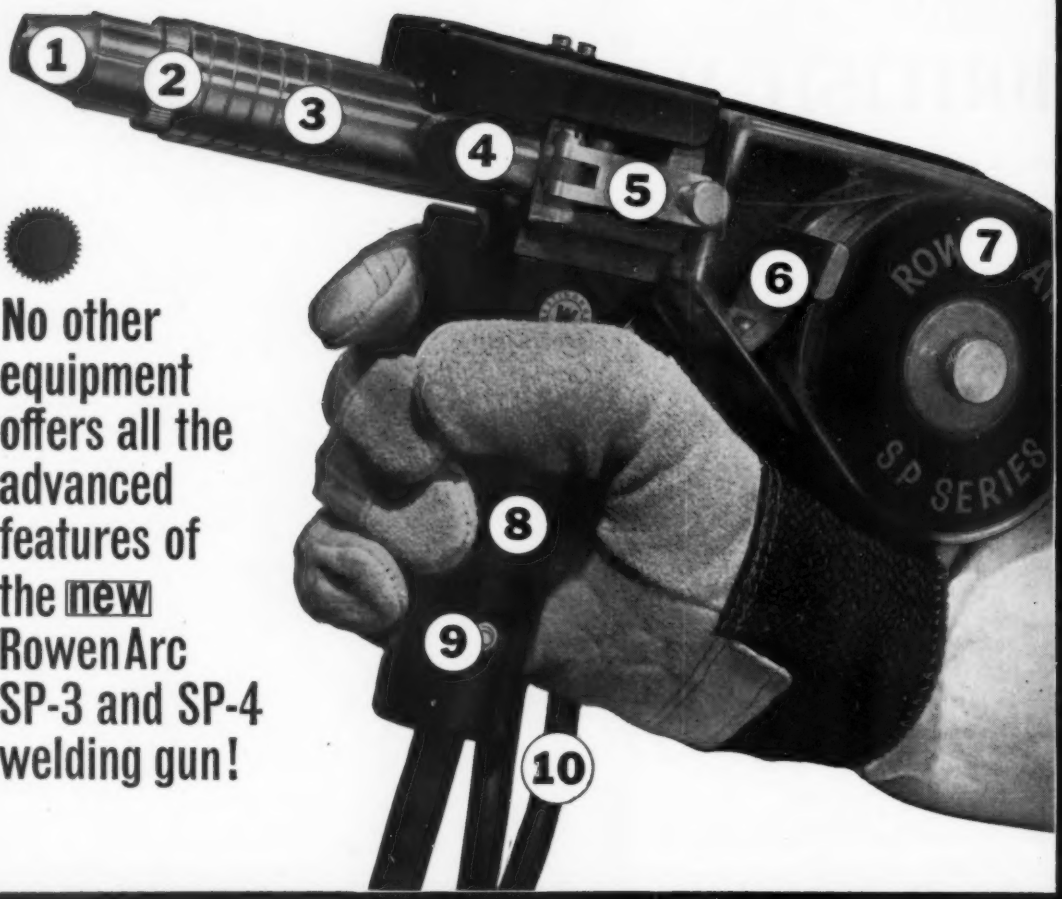

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Welding TECHNOLOGY

Metallurgical Concomitants of Residual Stress

By G. M. Boyd, O.B.E., M.R.I.N.A., A.M.I.STRUCT.E.

It is suggested that since residual stresses are inseparable from metallurgical changes in the material, the behaviour of a welded component, in regard to the transition temperature, should not be judged on the effects of the residual stresses alone.

It is shown that strain-ageing, quench-ageing, and other similar metallurgical changes that a steel undergoes during welding can most often cause the embrittlement that is ascribed to stress conditions.

Introduction

OVER the past two decades a great deal of research has been done, and an enormous literature has developed, on the effects of the residual stresses arising from welding on the behaviour of steel structures. This interest was stimulated mainly by the presumed association of residual stresses with brittle fracture, a subject which was brought into prominence by the outbreak of catastrophic brittle fractures in welded steel structures during and after World War II.[1,2,3]

Although the subject of residual stress has been well studied and ventilated, comparatively little attention has been given to the metallurgical effects which are inseparable from residual stress, yet these effects can hardly be a less important factor in the behaviour of structures than the residual stresses themselves. It is the object of this paper to review the literature on these metallurgical effects, and to indicate the directions in which further study may be fruitful.

Definitions

For the purpose of this paper, 'residual stresses' are defined as the stresses which remain within a steel structure when all external loads are removed. The paper is not concerned with residual stresses due to thermal gradients existing in the structure, which stresses would disappear at uniform temperature, nor with residual stresses due to the self-weight of the structure, the tightening of bolts or rivets, or peening, etc. It is mainly concerned with the residual stresses which arise directly from welding. Neither is it concerned with 'micro-stresses', *i.e.*, the residual stresses which are balanced on a grain-size scale. These are present in all solid metals, whether welded or not.

'Metallurgical effects' are defined as those changes which occur in the nature of a metal, and which affect its mechanical properties. Such effects include work hardening, strain-ageing, quench-ageing, grain growth and refinement, allotropic transformation and so on. Such changes need not necessarily imply any changes in microstructure detectable by the optical microscope. There is no primary concern with changes in chemical composition (although these are often associated with welding) nor with non-ferrous materials. The main interest is in ordinary mild steel.

Nature and Origin of Residual Stress

By definition, residual stresses must be self-balanced within the structure itself, since they exist in the absence of external loads or reactions. They are

Amplified version of a paper prepared for Commission IX of the International Institute of Welding, presented and discussed at the Annual Assembly in Liège, June 1960.

Mr. Boyd is with Lloyd's Register of Shipping.

consequently independent of these loads and reactions, except in so far as the application or removal of loads may in some circumstances modify the distribution of residual stresses.

It is sometimes convenient to distinguish the ordinary residual stresses which are localised to the vicinity of welds from the 'reaction stresses' which arise on a larger scale due to the lengthening or contraction of whole members of the structure. This distinction is purely a matter of convenience, and does not imply any essential difference in character.

Weck,[4,5] in a masterly analysis of the nature and origin of residual stresses, demonstrated that they can only arise from permanent changes in the shape of the body. This universal principle can be illustrated by the case of a simple 'anchor ring'. Consider a solid ring, which has been annealed so that it contains no residual stress. Imagine that a small section is cut away, leaving a gap.

Let the gap now be closed by applied forces, and the joint welded up invisibly and without metallurgical change. If the closing forces are now removed, the ring will contain residual stresses. The same effect can be obtained by 'upsetting' the ring in such a way as to introduce permanent plastic deformation. In this example, the ring has been permanently changed by cutting away material, upsetting, or otherwise deforming it. The principle established by Weck is that residual stresses cannot arise without such permanent changes.

The effect of this well-established principle, in relation to weld structures, is that the ordinary residual stresses which occur in the vicinity of welds can be produced only by the plastic flow that inevitably results from the uneven heating inseparable from welding. It may therefore be concluded that, if residual stresses exist in a welded component, then plastic deformation must have occurred, and this must have been associated with a temperature cycle involving temperatures up to the melting point of the material. Moreover, since it is well established that plastic flow and heat cycles of this order, occurring separately or together, result in metallurgical changes affecting the mechanical properties of steel, it must be concluded that residual stresses are inseparable from changes in mechanical properties extending into regions beyond the 'heat-affected zone' as normally defined. It may be observed here that this does not always apply to reaction stresses, which can arise from elastic changes in the length of members.

Some of the metallurgical effects likely to be associated with plastic flow and heat cycles may now be considered, without for the moment presupposing that these effects actually occur in any given case. Well known effects such as thermal hardening and 'contamination' (the dilution of weld metal by parent metal and vice versa) will not be considered.

Metallurgical Effects

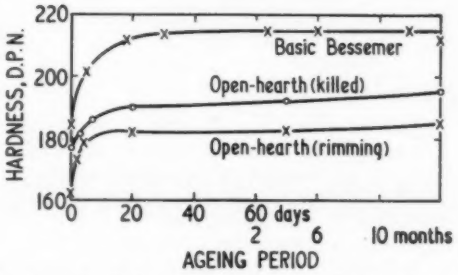
Grain growth and refinement

It is well known that steel, when subjected to high temperatures, suffers allotropic transformations and consequent changes in structure. These changes are usually manifested by changes in grain (crystal) size and are associated with changes in physical properties. The changes in metallurgical structure occur mainly within the weld metal and heat-affected zone as normally defined, *i.e.*, the zone in which the metal has been transformed. They therefore come within the domain of 'weldability' and do not require further detailed consideration here. It is necessary to remark, however, that allotropic transformations are associated with changes in volume, which in general result in residual stresses. These changes in volume may also induce plastic deformation outside the transformed zone, with consequent further residual stress and other effects to be discussed later.

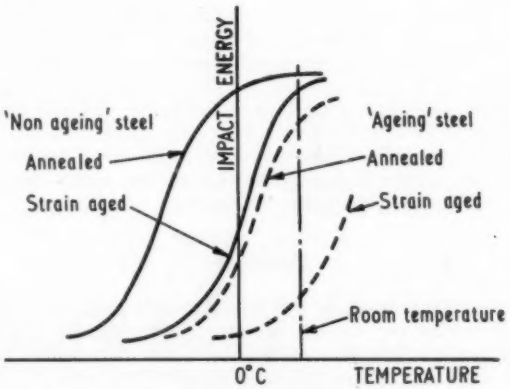
Strain ageing

Strain-ageing is one of a group of phenomena associated with precipitation effects within the metal. The delineations between these phenomena are by no means precise, and considerable differences in nomenclature occur in the literature.[6] An excellent survey of the subject in relation to iron and steel was given in 1939 by Kenyon and Burns,[7] and the literature is now very extensive. A very clear exposition has also been given by Dickie.[8] A much over-simplified description of strain-ageing for the benefit of the layman is as follows:

If a piece of annealed steel is strained beyond its elastic limit (say by 2% to 5%), and then it is allowed to rest, or 'age', it will be found that its properties have changed profoundly. The changes affect the magnetic, electrical, chemical (response to etching and corrosion), physical (density and crystallography), and



1—*Strain-age hardening at atmospheric temperature after pulling to max. stress in tensometer machine*[9]

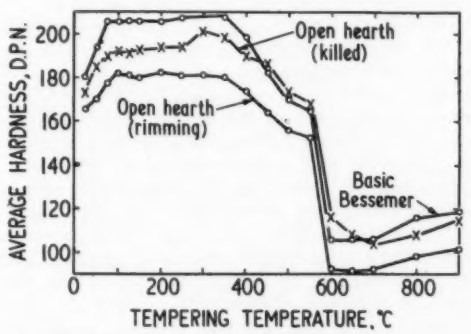


2—*Effect of ageing on transition temperature*

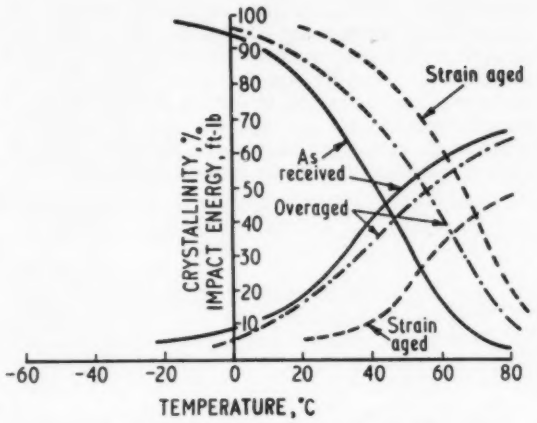
mechanical properties.[7] Among the latter, which are of main concern here, may be mentioned the hardness, yield phenomena, and impact properties. The hardness increases as indicated in Fig. 1. The yield point, which is abrupt in most annealed or normalised mild steels, almost disappears when the material is first strained, but returns and is increased after ageing. The effects on the impact properties are profound, as indicated in Figs. 4–6. The curve of energy absorbed versus temperature of testing is shifted bodily towards higher temperatures, resulting in much lower energies at a given temperature after straining and ageing. The shape of the curve is also modified, but generally not to a great extent. The main change is the shift just mentioned. The amount of the shift varies somewhat, but not greatly, between different steels, and may be anything from about 20° to about 40°C. Even steels which have been described as 'non-ageing' show similar shifts, but since in such steels the transition zone of the energy/temperature curve is initially well below room temperature, the effect on the impact energy at room temperature is small (*see* Fig. 2). This phenomenon has given rise to the term 'strain-age embrittlement', and is of first-rate importance in relation to the present context.

The length of the ageing process, *i.e.*, the period of rest following straining beyond the elastic limit, required to develop the full effect, is a function of temperature. At room temperature the period may be of the order of 10–14 days,[8] but at 250°C. the full effect is produced in about 1 hr. At higher temperatures the effect is not greatly accelerated, and at temperatures over about 600°C. the effect is very much reduced (*see* Fig. 3). Indeed, heating to about 650°C. and cooling slowly removes most of the effects of prior strain-ageing. This phenomenon is known as 'over-ageing'. It is specially noteworthy that the heat treatment (re-heating to 650°C. followed by slow cooling) known as 'stress relieving' is just that which is required to produce this over-ageing effect. This point will be referred to later.

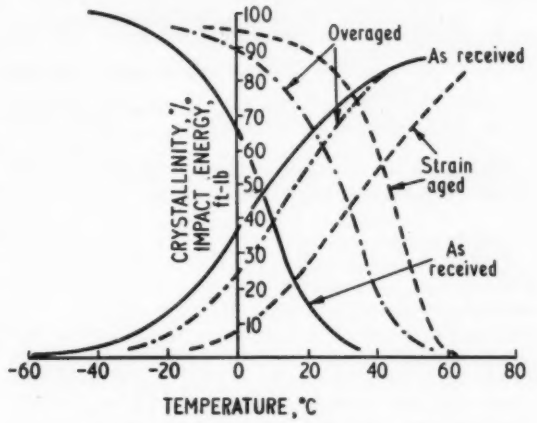
The behaviour of five types of mild steel on strain-ageing and subsequent over-ageing has been examined by Tipper.[9] Samples of each steel were strained 4–5% in tension, and the Charpy V-notch specimens machined from the samples were heated for 1 hr at 200°C. It was found that this treatment produced no change in microstructure detectable by the optical



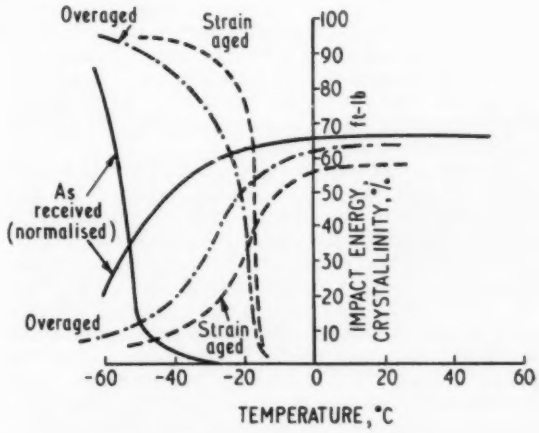
3—Effect of re-heating at various temperatures after pulling to max. stress in tensometer machine[6] (1 hr at each temp.)



4—Charpy V-notch test results for steel P



5—Charpy V-notch test results for steel Q



6—Charpy V-notch test results for steel T

microscope, but in all five steels the energy and crystallinity curves were shifted to the right, *i.e.*, towards higher temperatures. Other specimens, treated in the same way, were heat treated at 650°C. for 1 hr, and it was found that this treatment shifted the curves back to the left, but the recovery was not complete. The Charpy curves for three of the steels are shown in Figs. 4–6, and the results are summarised below:

	Shift to Right due to Strain-Ageing		*Recovery on Over-ageing at 650°C.*		*Permanent Shift*	
	Energy	% *Cryst.*	*Energy*	% *Cryst.*	*Energy*	% *Cryst.*
Steel P	25°C.	25°C	20°C.	10°C.	5°C.	15°C.
„ Q	27°C.	37°C.	18°C.	13°C.	9°C.	24°C.
„ R	45°C.	18°C.	15°C.	8°C.	30°C.	10°C.
„ S	25°C.	20°C.	18°C.	14°C.	7°C.	6°C.
„ T	35°C.	40°C.	13°C.	7°C.	22°C.	33°C.

It will be noted that, as compared with the energy, the crystallinity is generally affected rather more by strain-ageing, and its recovery is less on over-ageing.

Brief particulars of the five steels are as follows:

Steel P: Ordinary mild steel, semi-killed, as rolled
„ Q: 0·15% C 1% Mn steel, semi-killed, as rolled
„ R: 0·12% C 1·4%Mn steel, killed, grain controlled, normalised
„ S: 0·15% C 1% Mn steel, killed, grain controlled, normalised
„ T: 0·15% C 1·4% Mn steel, killed, grain controlled, normalised

All the steels were made by the open-hearth process, in the 26 to 32 tons/sq.in. tensile range.

Quench ageing

This is a similar effect to the strain-ageing just described, but it develops with time after quenching, without the necessity of prior straining. The maximum effect is produced when the steel is cooled from a high temperature, such as a welding or forging temperature, and is quenched out at about 600°C.[8] The effects are lessened as the temperature of quenching is lowered. The hardness develops over a longer period, of the order of 10 days. Quench-age embrittlement can be removed by re-heating to about 300°C.

It is important to note that both strain-age embrittlement and quench-age embrittlement are not accompanied by visible changes in metallurgical structure.

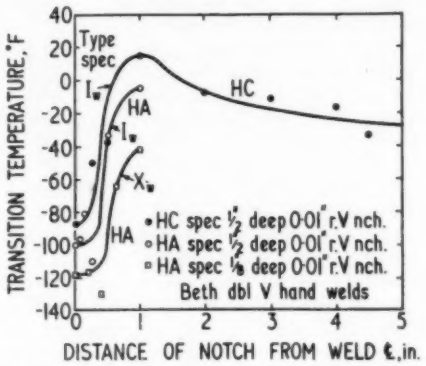
It is clear from the foregoing that in the vicinity of arc welds the conditions for both strain-age embrittlement and quench-age embrittlement are operative, though the two forms may occur in different zones, depending upon the extent of plastic straining and the temperature cycles experienced.

There is experimental evidence that embrittlement of the parent metal does in fact occur. This was shown clearly by Shepler[10] in 1946 by notched bend tests at varying distances from the weld centre. Fig. 7, reproduced from this paper, shows a peak of brittleness (high transition temperature) at about 1 in. from the weld centre, *i.e.*, well beyond the heat-affected zone as usually defined. The transition temperature at this peak was about 40°F. (22°C.) above that of the parent plate. The transition temperatures were determined by inspection of autographic load/deflection diagrams. The investigation was continued to determine the effects of varying welding procedures.[11]

The thickness of the plates referred to in Fig. 7 is not given in the original paper but the test specimens were 1 in. × 1 in. in cross section, suggesting that the original plate thickness was also 1 in.

The following passage, quoted from the paper[10] indicates the state of knowledge at the time (1946):

"The importance of the results as indicated by Fig. 7 cannot be overemphasised. Here is clearly shown that there is a very large difference between the transition temperatures of the material at various parts of the welded plate, the deposited metal at the centre being of excellent ductility while the base plate 1 in. away for this non-killed ship plate is very brittle. A glance at specimens Type I_w and X_w of Fig. 7 shows the bad point to be out of the zone of weld deposit material; clearly this 1 in. point can no longer be considered out of the heat-affected zone. Explanations by mechanical engineers and metallurgists will have to be advanced, methods to improve this condition will have to be found. Quite probably both theorising and experimenting will help the solution. Microscopic study



7—Effect of notch location on transition temperature

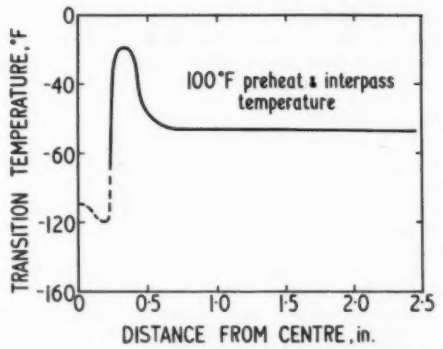
ought to be of immense aid. During the coming year it will be the full-time job of this laboratory with the present method to survey point-by-point welds made under various welding techniques and made on various baseplates in the attempt to find a weld with a curve lower down than those of Fig. 7.

"To date one possible explanation for the bad material at the 1 in. point has been advanced by Dr. A. B. Kinzel, namely, that it is the point of critical strain ageing. Other explanations on this point will be very interesting to consider."

Baldwin and Evans[12] and also Klinger and Ebert[13] made a special study of the brittle zone found in the sub-critically heated regions in the vicinity of welds in mild steel with the express object of obtaining an insight into the mechanisms responsible for this embrittlement. They concluded that quench-ageing was mainly responsible. The study was made with the aid of eccentrically loaded cylindrical notched tensile specimens 0·212 in. (5·4 mm) dia. under the notch, which was of the 60° V type with a depth of 0·044 in. (1·12 mm) and a root radius of 0·001 in. (0·025 mm). The eccentricity was ¼ in. (6·36 mm). The tests were carried out at various controlled temperatures, and the

transition temperatures were determined by plotting the load at fracture against temperature and taking the vertical mid-point between the high (ductile) and low (brittle) limbs of the curve. The type of result obtained is shown in Fig. 8, indicating a peak of brittleness just beyond the heat-affected zone, as found by Shepler.[10,11] This discovery of an embrittled zone in a region which could not have been heated above the lower critical temperature led the investigators to examine whether this could be reproduced by sub-critical heat treatment in the absence of welding. They succeeded in doing this by a quench-ageing treatment and concluded that this mechanism was mainly responsible. They then pointed out that 'over-ageing' by post-heating at about 650°F. (350°C.) would minimise the embrittlement.

It is interesting to note that Baldwin and Evans did not apparently include straining and ageing in their efforts to reproduce the effect. Presumably, if they had done so and found strain-ageing to be a factor, they would have recommended post-heating at 1200°F. (650°C.) as a remedy.



8—*Variations of transition temperature with distance from weld centreline*[12]

There is also evidence that plastic flow, even in the absence of ageing, can have a serious embrittling effect. This has been pointed out by Mylonas *et al*[14–16] who made notched tensile tests on material which had been previously prestrained in compression; they found a marked reduction in stress to rupture.[16] They also made plain tensile tests on prestrained material, and found marked reductions in strength and ductility. One such plain tensile specimen (0·505 in. dia., 2 in. gauge length), fractured at 80°F. (27°C.) gave a brittle fracture with only 1·7% elongation. The important feature of these plain tensile tests is not only the small strain and brittle character of the fractures, but also that the effects were found in the absence of any notch or residual stress, and at the top end of the transition temperature range of the virgin material.

Vinckier[19] produced 'spontaneous' fractures in discs of steel containing central square holes welded into heavy annular restraining frames. Owing to the heavy restraint, the inner disc underwent severe plastic deformation during welding, and high residual stresses were thereby induced. One specimen was stress relieved at 620°C. after welding, and this specimen did not fracture. The same specimen was then heated locally to 600°C. producing new plastic flow and residual stresses. A fracture was then produced on local cooling in liquid nitrogen. It was argued that the beneficial result of stress-relief heat treatment in this case was due to the relief of stress and not to metallurgical effects. This argument is, however, open to question, since the method used to introduce residual stress cannot have failed to produce metallurgical changes of the kind discussed here. Similarly, the heat treatment applied would not only reduce the stresses but improve the metallurgical condition, owing to the 'over-ageing' effect mentioned.

Directionality

There are indications, though these are not very definite, that the effects of strain-ageing, and also the 'exhaustion of ductility' due to plastic deformation[14–16] are directional, *i.e.*, their effects are greatest in the direction in which the strain is applied, so that the effect would act in the same sense as the co-existing residual stresses. This directional effect could, of course, influence the direction of fractures, and may account for the observed tendency for fractures to be deviated from their normal directions when they occur in the vicinity of welds. The matter, however, requires further investigation.

Service Experience

Many of the studies which have been made on service failures in welded structures[2,20,21] have drawn attention to the fact that the majority of the fractures have originated at welds, and mostly at welds lying in a direction parallel to that of the principal applied stresses. The fractures, however, seldom follow the welds, but tend to run off into the parent plate.

While many of these fractures may have originated from defects or cracks—particularly transverse cracks—in the weld metal, it is also known that many have originated from apparently sound welds. This latter tendency has in the past been attributed to the high tensile residual stress parallel to the length of the weld, and this possibility has been specifically examined by Wells.[22] Whilst the residual stresses undoubtedly contribute to the initiation of fractures running transversely from welds laid parallel to the main stresses, the explanation becomes more convincing if the existence of a metallurgically embrittled zone is accepted. There is, however, no satisfactory means at present available for separating the mechanical effects of residual stress from the co-existing metallurgical embrittlement, particularly in relation to service fractures.

Soete[24] has shown conclusively, by an extensive series of experiments, that residual stresses alone are incapable of accounting for the low-stress brittle fractures which have been observed in the laboratory and in service. To explain these it is also necessary to postulate local metallurgical embrittlement of the material. He found that the capacity of the material to deform was more important than the residual stress, which plays only a secondary role.

Summary and Discussion

It has been shown that the residual stresses due to welding cannot arise without plastic flow. Also,

plastic flow, in association with the temperature cycles of welding, and the elapse of time, produce both quench-ageing and strain-ageing in mild steel. It has also been shown that these ageing effects have a marked embrittling effect in that they considerably raise the transition temperature of the steel. It follows therefore that residual stresses cannot exist without embrittlement in a region which extends considerably beyond the heat-affected zone as normally defined.

It has also been shown that embrittlement does in fact occur, and that it can be greatly ameliorated by heat treatment, and particularly by the heat treatment known as 'stress relieving', *i.e.*, heating to about 650°C. and cooling slowly.

This finding has several important consequences, among which the following may be mentioned:

(1) A new definition of 'heat-affected zone' is required. It is suggested that the term should be applied to the region in which any changes in mechanical properties have occurred as a result of the operation of welding. Such a zone would be considerably wider than the 'transformed zone', *i.e.*, the zone in which the metal has undergone allotropic transformation as a result of the heat of welding.

(2) Many of the effects observed experimentally and in service, which in the past have been attributed simply to residual stress, should be more properly attributed to a combination of residual stress and metallurgical changes (quench-ageing, strain-ageing, and exhaustion of ductility due to plastic flow).[17]

(3) In particular, the initiation of brittle fractures at low stress from welds, in the absence of a defect, can be more satisfactorily explained as due to a combination of residual stress and the local embrittlement due to the afore-mentioned metallurgical changes.[18, 24]

Indeed, it is probable that some of the low-stress fractures which have been observed in experiments and in service might not have occurred under the influence of residual stress alone, if the metallurgical embrittlement had not been present.[24]

(4) Remedial measures should be considered not only on the basis of residual stress, which could be relieved by essentially mechanical methods, but also on the basis of metallurgical embrittlement, which can be ameliorated only by suitably chosen heat treatment.

It is important to remember that the heat treatment which is most suitable for the removal of stresses may not be the most suitable from the metallurgical viewpoint. There is some evidence that prolonged soaking at 650°C., which seems desirable from the standpoint of stress relief, may nullify the over-ageing, and would result in failure to remove the embrittlement due to strain-ageing and quench-ageing. This point requires further study, to determine the optimum temperatures and times that would ensure the best results.

(5) Although quantitative assessment is difficult or impossible, it is evident that the metallurgical effects are at least equal in importance to the residual stresses, and therefore merit at least equal attention.

It is relevant to quote the following conclusion of the U.S. Weld Stress Committee, embodied in their final report.[23]

"Stress relieving treatments, particularly thermal, have been proved to be beneficial in so far as the quality of a welded joint is concerned, and are still considered a necessity in many structures, as, for example, pressure vessels, machinery parts and the like. The beneficial effects are not primarily due to reduction of residual stresses, but rather to improvement of metallurgical structure, dimensional stability in machining operations and reduction in stress corrosion potentialities."

Acknowledgment

The author warmly acknowledges the assistance of Dr. A. A. Wells and Dr. C. L. M. Cottrell in the preparation of this paper, without, however, committing them to the views expressed. The assistance of Dr. C. F. Tipper, who has in the past frequently drawn attention to the importance of these metallurgical effects, is particularly acknowledged.

Figures 1 and 3 are re-drawn from Ref. 8; Fig. 7 from Ref. 10, and Fig. 8 from Ref. 12.

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Welding RESEARCH

B.W.R.A. REPORT

Argon–Nitrogen Mixtures for the Self-Adjusting Arc Welding of Copper

By J. G. Young, B.SC.

The influence of gas composition on metal transfer and penetration in the copper self-adjusting arc has been examined for argon, nitrogen, and mixtures of the two gases.

It is shown that for currents below the threshold value in argon (310 amp), the metal transfer rate in mixtures containing from 5% to 33% nitrogen is higher than the transfer rate in argon. It is concluded that argon-rich mixtures give greater penetration and higher metal transfer rates than pure argon.

THE effect of current on metal transfer characteristics in the aluminium self-adjusting arc is now well known;[1] the existence of a 'threshold current' has been demonstrated, below which metal transfers in the form of large globules and above which 'spray' type transfer occurs. It is reasonable to suppose that a similar effect occurs in the copper arc, and the work of Moore and Taylor[2] suggested that the threshold exists at about 310 amp for $\frac{1}{16}$ in. dia. copper wire in argon. In nitrogen, spray transfer was not obtained, and although sound welds in the downhand position were possible, the appearance of such welds was not altogether satisfactory owing to the low rate of metal transfer. Nitrogen does, however, offer considerable benefits in cheapness and in greatly improved penetration owing to the heat developed by the dissociation-recombination reaction $N_2 \rightleftharpoons 2N$.

The work described was designed to provide quantitative information on metal transfer and penetration in argon and nitrogen and in various mixtures of the two, to see whether it was possible to combine the greater penetration of the arc in nitrogen with the superior transfer characteristics of the arc in argon.

Experimental Work

All the experimental work was carried out on a mechanised self-adjusting arc welding head with a constant-potential power source using d.c., electrode positive. The argon and nitrogen supply was regulated at the cylinders and, where necessary, combined in a mixing chamber before being supplied to the welding head. The $\frac{1}{2}$ in. dia. nozzle was held at a forehand angle of 80° and positioned with its trailing edge $\frac{1}{2}$ in. above the plate surface. All deposits were made on $\frac{3}{16}$ in. thick deoxidised copper plate, and the traverse speed was maintained at a constant value which, in the case of the penetration measurements, was 22·5 in./min, the plate size being 6 in. × 3 in. with the bead in the centre.

Current and voltage readings were made on recording instruments and, to determine the rate of metal transfer, oscilloscope records of voltage were obtained using a high-speed camera. Wire feed rates for burn-off-rate curves were determined from measurements of drive roll revolutions and weld times.

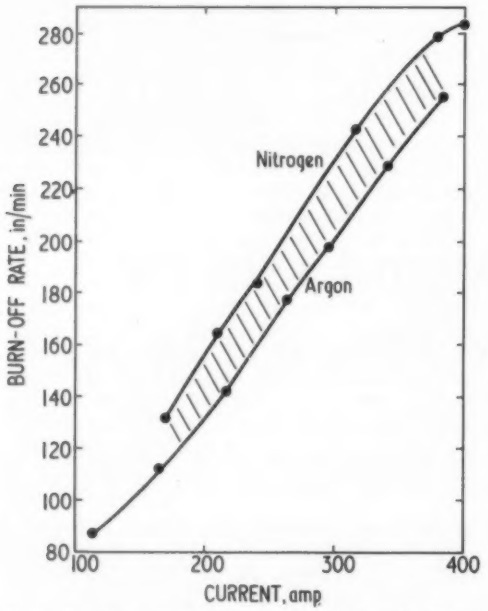
The arc voltage was maintained at a constant value of 30 V, except for a series of tests in argon at 25 V to determine the effect on transfer rate of changes in arc voltage. Variations in current were made by alterations to the wire feed speed, only minor adjustments to the open circuit voltage of the generator being necessary to give a constant arc voltage.

Report C3/1/58 of the British Welding Research Association, circulated to members in January, 1961.

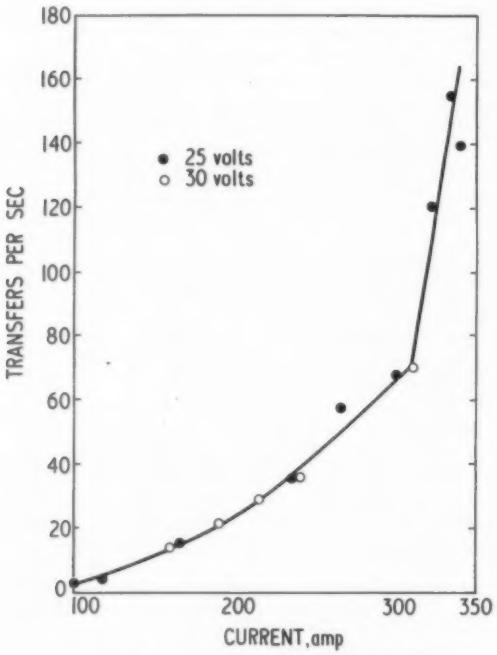
Mr. Young is a Principal Research Officer with the Association.

The gases examined were as follows:

1. Pure argon
2. Pure nitrogen (oxygen free)
3. 50% argon–50% nitrogen by volume
4. 67% argon–33% nitrogen " "
5. 80% argon–20% nitrogen " "
6. 95% argon–5% nitrogen " "



1—*Burn-off-rate curves for $\frac{1}{16}$ in. dia. type 1 wire in argon-nitrogen mixtures*



2—*Effect of arc length on metal transfer in argon*

Some additional experiments were made using 85% argon–15% nitrogen and 90% argon–10% nitrogen mixtures. The total gas flow in all cases was 50 cu.ft/hr The filler wire used in all experiments was $\frac{1}{16}$ in. dia. Si–Mn deoxidised copper.

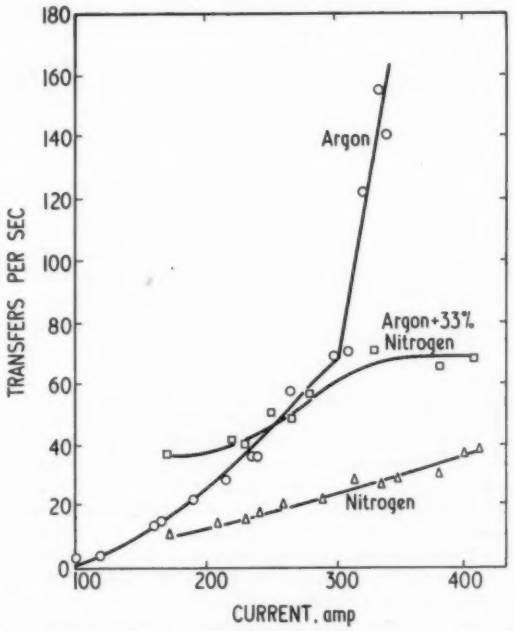
Results

Burn-off rate

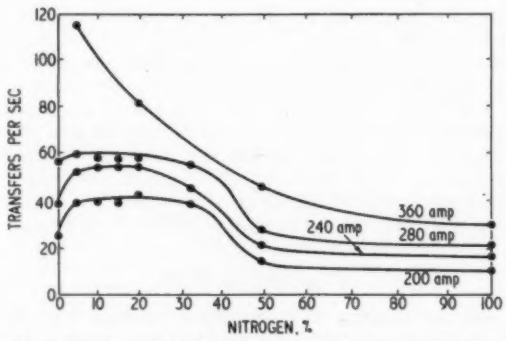
Burn-off-rate curves for $\frac{1}{16}$ in. dia. wire are given in Fig. 1. The lower line represents the characteristic in argon and the upper line the characteristic in nitrogen. Values for the various mixtures fall in the shaded area between the lines.

Metal transfer characteristics

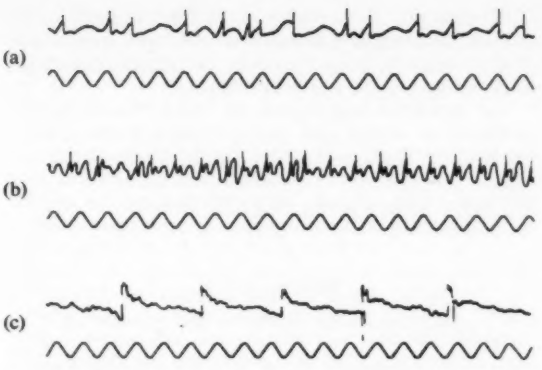
Results for pure argon at 25 V and 30 V are given in Fig. 2. It is possible to draw a common line through



3—*Metal transfer characteristics in argon, nitrogen, and argon–33% nitrogen*

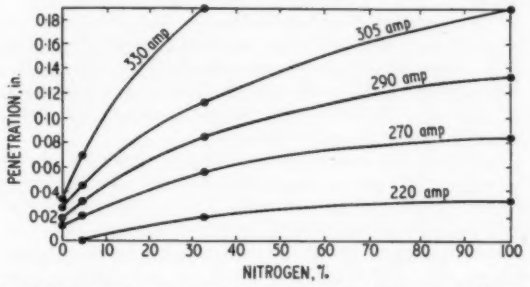


4—*Transfer characteristics of type 1 wire in argon–nitrogen mixtures at selected current levels*



5—*Oscillograms for 230–240 amp arc in*: (a) *Pure argon—39 transfers per second;* (b) *argon–5% nitrogen—53 transfers per second;* (c) *pure nitrogen—17 transfers per second*

points at both voltage levels, and it may be concluded, provided that short circuits do not occur, that arc length has no significant effect on transfer rate.



6—*Influence of gas composition on penetration at different current levels*

7—*Effect of shielding gas composition on appearance of weld beads on* $\frac{3}{16}$ *in. copper at 45 in./min*

Although the number of transfers occurring in the sub-threshold region is considerably greater than in the case of an aluminium arc, there is a distinct change in slope of the transfer characteristic at 310 amp, confirming the observations made by Moore and Taylor.[2]

The transfer characteristics of the filler wire in nitrogen and in one of the gas mixtures (67% argon–33% nitrogen) are compared with the argon characteristic in Fig. 3. The sub-threshold nitrogen characteristic is also shown; there is no tendency for spray transfer to occur up to 410 amp.

It is not convenient to plot the transfer characteristic for each gas mixture in this way, the preferred method being to plot transfer rate against gas composition at selected current levels (Fig. 4).

For currents below the threshold level in pure argon, *i.e.*, 310 amp, gas mixtures containing from 5 to 33% nitrogen give higher rates of metal transfer than pure argon. In this region gas composition is not critical, the curves showing a flat-topped peak. The effect is demonstrated in Fig. 5, which reproduces oscilloscope records for a 230–240 amp arc in (*a*) argon (*b*) argon–5% nitrogen, and (*c*) nitrogen. Here the rate of transfer is evidenced by the number of upward 'flicks' or open circuits on the voltage trace. The sine curve on these oscillograms is a 50 c/sec time base.

Penetration

In Fig. 6 the relationship between penetration and gas composition at five current levels is shown for bead-on-plate tests. The increase of penetration with increasing nitrogen content is not linear, mixtures containing 33% nitrogen giving a disproportionately large increase in penetration. For example, for a current of 290 amp the penetration in argon+33% nitrogen is 4·5 times the penetration in pure argon, whilst in pure nitrogen penetration is 7·5 times that in argon. The effect of nitrogen additions is again illustrated in Fig. 7 which shows the appearance of weld beads made at similar current levels with various shielding gases. It is evident that under the particular test conditions employed (45 in./min travel speed) it was not possible to maintain a molten pool in argon at 360 amp, although a bead of good appearance was made at 350 amp with the addition of only 5% nitrogen.

Discussion

The remarkable feature of the results is the discovery of the existence of a gas composition range giving higher metal transfer rates than pure argon in the sub-threshold current range.

The threshold level in pure argon is confirmed at 310 amp, currents of this value and below giving 70 transfers or less per second and higher currents giving 120 transfers or more per second. However the threshold is much less significant than in the case of aluminium, and use can be made of arcs giving only 40 transfers per second; in argon this corresponds to a 240 amp arc. In gas mixtures containing from 5% to approx. 30% nitrogen the corresponding current for 40 transfers per second is only 200 amp.

Penetration is increased as nitrogen content increases, and small quantities of nitrogen give a disproportionately large increase in penetration, 33% nitrogen giving the optimum increase.

The practical significance of these results is that mixtures of argon and nitrogen give much greater penetration than pure argon, without the disadvantages of the low rate of metal transfer obtained in pure nitrogen. The results indicate that the optimum composition is in the range 20–33% nitrogen.

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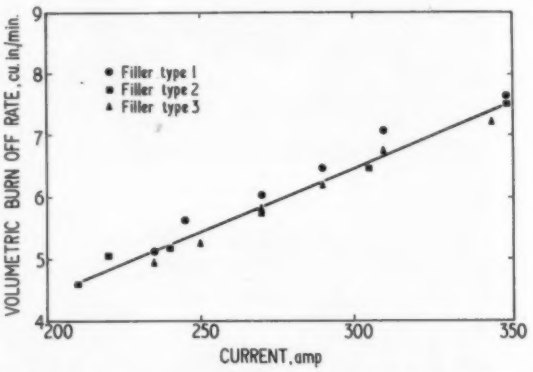
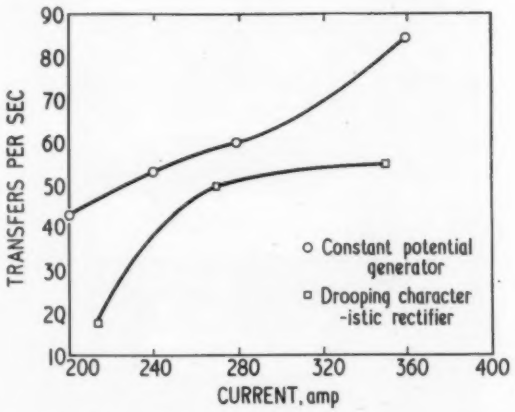
APPENDIX

Subsequent to the preparation of this report, some additional work has been carried out on the influence of filler wire composition and on power source characteristics.



8—Burn-off characteristics of three commercial $\frac{1}{16}$ in. dia. filler wires in 80–20 argon–nitrogen mixture



9—Influence of power source slope on transfer frequency. Type 2 wire in 80–20 argon–nitrogen mixture

Filler wire composition

Three types of filler wire are available to the following British Standards:

Type 1—BS.2901/C7
Type 2—BS.2901/C21
Type 3—BS.2901/C8

They were studied in argon–nitrogen mixtures, and burn-off rates for $\frac{1}{16}$ in. dia. wire in an 80–20 argon-rich mixture are given in Fig. 8. It will be noted that there is no significant difference between the behaviour of the three wires in the range 210–350 amp.

In so far as metallurgical quality is concerned, Type 1 wire gave porous welds, and with Type 3 oxide film entrapment was a problem. Type 2, on the other hand, gave sound welds of good appearance and is preferred for gas mixtures.

Power source characteristic

The work covered in the main report was carried out using a constant-potential motor generator set of 300 amp capacity. Some experiments have been made using a 400 amp drooping characteristic rectifier to verify whether the constant-potential power source is essential.

Results given in Fig. 9 suggest that the constant-potential power source does give superior transfer characteristics (*i.e.*, higher transfer frequency at a given current) to the drooping characteristic rectifier in an 80% argon–20% nitrogen shielding gas. The explanation of this phenomenon must await the results of more fundamental work on metal transfer.

B.W.R.A. REPORT

Inert Gas Shielded Metal Arc Welding of Thick Copper without Preheat

By K. J. Clews

One of the major obstacles to the more widespread use of thick copper weldments in industry is the need for a high temperature preheat, owing to the high thermal conductivity of the metal. Preheating temperatures up to 800°C. may be necessary for 1 in. thick metal.

Tests carried out on $\frac{1}{2}$ in. thick phosphorus-deoxidised copper have shown that the use of argon–nitrogen mixtures in place of pure argon enables preheat temperatures to be reduced, or welding speed to be increased, whilst the application of the twin consumable electrode process to the downhand welding of $\frac{1}{2}$ in. thick non-preheated copper has been demonstrated.

Introduction

On consideration of the physical properties of copper, the need for preheat when welding is apparent, and it is instructive to assess the size of the problem. Twice as much heat is required to melt unit volumes of copper, and three times in the case of iron, as is required to melt unit volumes of aluminium. On this consideration alone, since aluminium is readily weldable, it might be inferred that copper would be somewhat easier to weld than iron. However, when thermal conductivity is taken into account, it is demonstrable that it is as easy to form a weld pool of a given size in iron as in aluminium, and three times more difficult in copper.

One of the means of increasing the heating efficiency of the arc lies in the use of a diatomic shielding gas, and for copper nitrogen is usually chosen. With nitrogen shielding and tungsten-arc welding, $\frac{3}{16}$ in. thick copper can be joined in one pass without preheat as compared with $\frac{1}{8}$ in. thickness under argon shielding. The thickness of plate weldable by the shielded metal-arc process in one pass without preheat is about $\frac{5}{16}$ in. in nitrogen, or about $\frac{3}{16}$ in. in argon.[1,2] Of the gas-shielded welding processes, therefore, only the shielded metal-arc process appears to be of practical value in welding thick copper. Nitrogen shielded metal-arc welds are marred by spatter as a result of the coarse droplet transfer characteristic of the process. On the other hand, spray transfer of metal is obtainable in argon, and spatter is absent or very slight.

Young[3] has shown that it is possible to effect a compromise between heating efficiency of the arc and reduction in spatter by mixing argon and nitrogen, and the present report describes the results of practical

Report C3/5/60 of the British Welding Research Association, circulated to members in January 1961.

Mr. Clews is a Senior Experimental Officer with the Association.

Table I

Single electrode beads-on-plate in argon

Weld No.	Current, amp	Arc Voltage, V	Wire Feed Speed, in./min	Travel Speed, in./min	Average Dimensions of Bead, in. Penetration	At max. width	Height of reinforcement	Remarks
1	340	18	250	40	0·04	0·24	0·08	Intermittent bead
2	,,	21	245	,,	0	0·32	,,	
3	360	20	275	,,	0·08	,,	,,	
4	,,	30	245	,,	0	0·20	0·12	
5	400	26	270	,,	,,	0·32	,,	
6	,,	27	,,	,,	0·06	0·20	0·14	
7	440	28	290	,,	0·12	0·32	,,	
8	450	23	,,	,,	0·08	,,	0·16	Tunnelling
9	480	22	315	,,	0·16	0·24	0·18	
10	,,	24	,,	,,	0·04	0·40	0·20	Gross porosity
11	540	22	340	,,	0·16	0·32	0·18	Tunnelling
12	,,	,,	395	,,	0·24	0·20	0·24	,,
13	,,	27	340	,,	0·12	0·36	,,	Gross porosity
14	550	26	,,	,,	0·08	,,	0·22	Tunnelling
15	560	22	370	,,	0·20	0·16	0·24	,,
16	570	23	,,	,,	0·16	0·32	0·26	Gross porosity, Tunnelling
17	580	23	395	,,	0·08	0·20	0·24	,, ,,

trials on ½ in. plate with mixed gas shielding. A further aim of the work has been to determine whether preheat can be reduced or even dispensed with when welding ½ in. thick copper in argon.

Single-Wire Inert-Gas Metal-Arc Welding

Experimental

To investigate the potentialities of the inert-gas metal-arc process in welding thick copper without preheat, bead-on-plate runs were made on ½ in. thick phosphorus-deoxidised copper plate measuring 12 in. × 6 in. The filler wire was $\frac{1}{16}$ in. dia. boron-deoxidised copper, which has been shown to be the only commercially available filler alloy fully effective in gas mixtures. Welding equipment was conventional and consisted of a 600 amp rectifier power source with a drooping characteristic used in conjunction with a stationary welding gun which was directed vertically downwards at the work piece mounted on a motor-driven carriage.

Tests were carried out in argon, nitrogen, and mixtures of the two gases. Current, wire feed speed, and travel speed were varied, and the dependent arc voltage was measured. After welding, the plates were sectioned, polished, and etched, and the depth of penetration, amount of reinforcement, and weld width were measured. The nature and extent of porosity were also investigated, and these results together with welding conditions and weld measurements are recorded in Tables I–IV. which refer to welds in argon, argon–nitrogen, nitrogen–argon, and nitrogen shielding respectively.

Results

The tables show that, in general, penetration of the parent metal increased as current increased but that penetration amounted to no more than 0·25 in. with

Table II

Single electrode beads-on-plate in 80–20 argon–nitrogen mixture

Weld No.	Current, amp	Arc Voltage, V	Wire Feed Speed, in./min	Travel Speed, in./min	Average Dimensions of Bead, in. Penetration	At max. width	Height of reinforcement	Remarks
18	400	28	370	20	0·06	0·32	0·14	
19	480	30	,,	,,	0·12	0·36	0·16	
20	500	29	395	,,	0·24	0·20	0·18	
21	,,	38	370	,,	0·12	0·52	0·16	Tunnelling
22	280	25	235	40	0·02	0·20	0·10	Porosity
23	310	,,	245	,,	0·08	0·34	0·08	
24	330	30	,,	,,	0·04	0·32	0·04	
25	370	28	270	,,	0·02	0·28	0·12	
26	380	22	,,	,,	0·04	0·36	0·08	
27	,,	35	,,	,,	—	0·52	,,	Intermittent bead, Porosity
28	400	28	315	,,	0·10	0·24	0·12	Tunnelling
29	420	30	,,	,,	0·16	0·32	0·18	,,
30	440	28	370	,,	0·20	,,	0·24	,,
31	480	31	,,	,,	0·18	0·28	0·22	,,
32	520	34	395	,,	0·12	,,	0·18	
33	540	37	,,	,,	,,	0·36	0·16	
34	550	32	450	,,	,,	0·32	0·22	Tunnelling
35	560	36	425	,,	0·16	0·36	0·20	,,
36	570	,,	450	,,	0·24	0·44	0·22	,,

Table III

Single electrode beads-on-plate in 85–15 nitrogen–argon mixture

Weld No.	Current, amp	Arc Voltage, V	Wire Feed Speed, in./min	Travel Speed, in./min	Average Dimensions of Bead, in. Penetration	At max. width	Height of reinforcement	Remarks
37	460	22	340	40	0·20	0·28	0·20	
38	480	29	,,	,,	0·14	0·24	0·14	
39	500	28	370	,,	0·12	0·28	0·16	Porosity

Table IV

Single electrode beads-on-plate in nitrogen

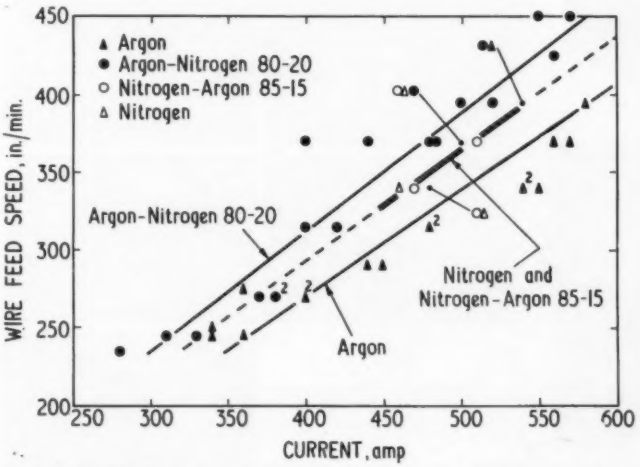
Weld No.	Current, amp	Arc Voltage, V	Wire Feed Speed, in./min	Travel Speed, in./min	Average Dimensions of Bead, in. Penetration	At max. width	Height of reinforcement	Remarks
40	470	24	340	40	0·14	0·28	0·16	Gross porosity
41	480	29	,,	,,	0·12	0·32	0·14	Porosity
42	500	23	370	,,	0·16	0·24	0·20	
43	510	28	,,	,,	0·14	0·32	0·16	

currents as high as 550 amp. The defect known as tunnelling[4] was associated with the higher welding currents. In argon a somewhat higher welding current—about 450 amp—could be employed before the onset of tunnelling than in the gas mixtures or in nitrogen, with which the defect occurred at about 350 amp.

Values of wire feed speed from the tables are plotted against current in Fig.1. Although there is considerable scatter in the observations, owing to uncontrollable changes in arc voltage, it is clear that the filler wire burn-off rate, as measured by wire feed speed, is greater in an 80–20 argon–nitrogen mixture at a given current than in pure argon. The burn-off rate in nitrogen appeared to be similar to that in 85–15 nitrogen–argon and intermediate between that in argon and in 80–20 argon–nitrogen.

2—*Bead-on-plate in argon*

3—*Bead-on-plate in nitrogen*



1—*Relationship between wire feed speed and current in argon–nitrogen atmospheres*

4—*Longitudinal section of bead-on-plate, showing tunnelling and porosity*

Table V

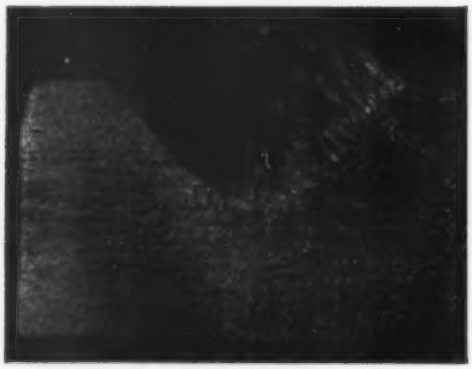
Two-wire beads-on-plate in argon

Weld No.	*Refer to Fig. 7*	*Travel Speed, in./min*	*Separation at Plate Surface of Electrode Wires, in. (Fig. 6)*	*Dimensions of Bead, in.* *Penetration*	*At max. width*	*Reinforcement*	*Remarks*
44	*a*	9	0	0·10	0·88	0·18	
45	*b*	,,	0·125	0·16	0·84	0·26	Tunnelling
46	*c*	12	0	0·21	0·82	0·82	
47	*d*	,,	0·25	0·16	0·88	0·17	Guns tilted 10° forehand
48	*e*	,,	,,	,,	0·76	0·20	
49	*f*	,,	0·75	0·28/0·14	1·15	0·22	W shaped bead
50	*g*	,,	1·0	0·24/0·12	0·50/0·43	0·24/0·18	Separate beads

Welding conditions: Current 400 amp, Arc voltage 25 V } Both guns
Wire feed speed 280 in./min (Rectifier) and 245 in./min (Generator)
Argon flow 25 cu.ft/hr through each gun

Clearly, from the results of the bead-on-plate trials, the conventional methods of welding thick copper are unlikely to be successful, even with argon–nitrogen mixtures, unless a high level of preheat is used.

It was considered, from examination of polished and etched sections of beads-on-plate, examples of which are shown in Figs. 2, 3, and 4, that the shape of the weld pool could be expected to promote turbulence as compared with a weld pool in preheated plate (Fig. 5); it is further evident that control of the shape of the molten pool during welding is of importance in preventing tunnelling. One possible alternative to preheat for the control of the form of the molten pool is to use twin consumable electrodes, and work on this aspect is covered in the following section.



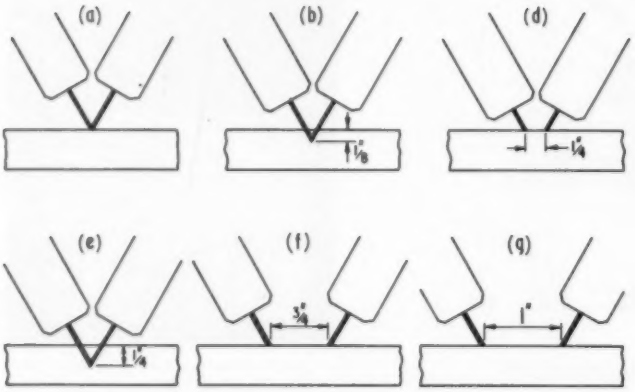
5—Bead-on-plate in argon. Preheated plate

Two-Wire Inert-Gas Metal-Arc Welding

Some work[5] has been done in Russia on the semi-submerged-arc welding of thick aluminium plate with twin wire electrodes. Unpublished B.W.R.A. work has shown that the twin consumable electrode process can be applied successfully to the inert-gas shielded welding of aluminium. It was evident from these investigations that two consumable electrode arcs might have a beneficial effect on the shape of the molten pool when welding copper, and accordingly tests were carried out to investigate the applicability of the method.

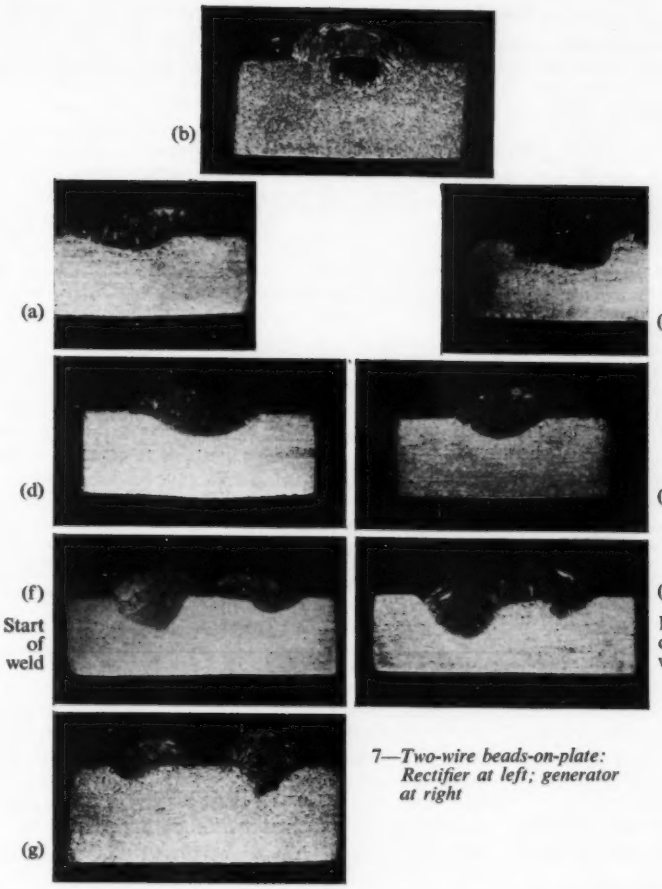
Experimental

The equipment employed was as described in the earlier part of this report with the addition of a second welding gun having a transformer-rectifier with a flat characteristic as its power source, and with a constant-potential 750 amp motor generator substituted for the drooping characteristic generator, so as to enable both arcs to operate more nearly at the same conditions. The wire feed speed settings for the two guns when arcs were running at 400 amp and 25 V were 280 in./min with the rectifier power source, and 245 in./min with the generator. In all the experiments described



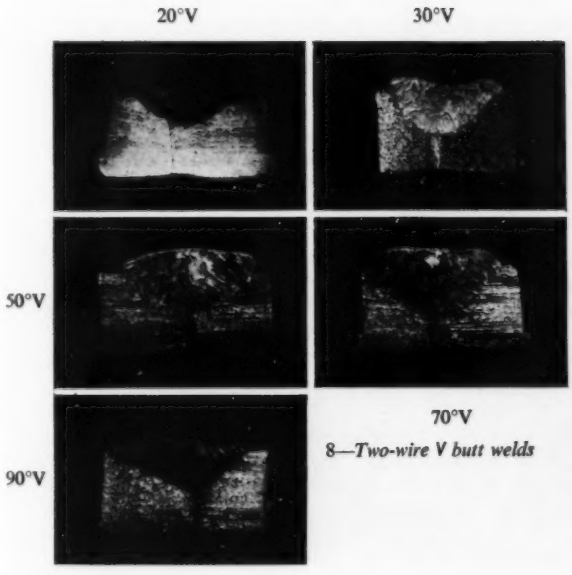
(*a*) See Figs. 7*a*, *c* and Welds 44 and 46 Table V
(*b*) See Fig. 7*b* and Weld 45 Table V
(*d*) See Fig. 7*d* and Weld 47 Table V
(*e*) See Fig. 7*e* and Weld 48 Table V
(*f*) See Fig. 7*f* and Weld 49 Table V
(*g*) See Fig. 7*g* and Weld 50 Table V

6—Arrangement of guns for two-wire bead-on-plate experiments

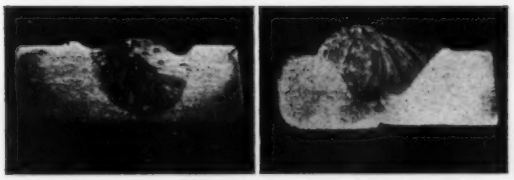


(*a*) See Fig. 6*a* and Weld 44 Table V
(*b*) See Fig. 6*b* and Weld 45 Table V
(*c*) See Fig. 6*a* and Weld 46 Table V
(*d*) See Fig. 6*d* and Weld 47 Table V
(*e*) See Fig. 6*e* and Weld 48 Table V
(*f*) See Fig. 6*f* and Weld 49 Table V
(*g*) See Fig. 6*g* and Weld 50 Table V

7—*Two-wire beads-on-plate: Rectifier at left; generator at right*

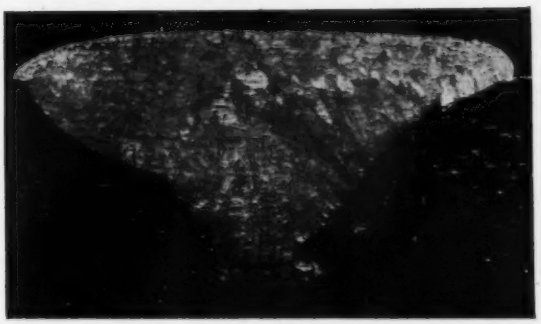


8—*Two-wire V butt welds*



Weld 56 Weld 57

9—*Two-wire U butt welds*



10—*Single pass two-wire weld in unpreheated ½ in. thick copper plate*

Table VI

Two-wire welds on chamfered plates in argon

Weld No.	Details of Weld Preparation: Root Face	Included Angle	Dimensions of Bead, in.: Penetration	At max width	Reinforcement	Remarks
51	0·25	20°	0·22	1·38	0·16	Good washing in at sides, no root fusion
52	,,	30°	0·28	0·80	0·12	Good washing in at sides, better penetration
53	,,	50°	0·24	0·88	0·16	Excellent washing in at sides
54	,,	70°	0·36	,,	0·14	,, ,, ,, ,,
55	,,	90°	0·30	,,	,,	,, ,, ,, ,,

Welding conditions: Ends of electrodes initially set to touch 0·125 in. below plate surface
Current 400 amp, Arc voltage 25 V } Both guns
Wire feed speed 280 in./min (Rectifier) and 245 in./min (Generator)
Argon flow 25 cu.ft/hr through each gun
Travel speed 12 in./min

Table VII

Two-wire welds in argon with U preparation

Weld No.	Travel Speed, in./min	Dimensions of U Preparation, in.: Width at Plate Surface	Depth	Root Face	Radius at Root	Dimensions of Bead, in.: Penetration	At max. width	Reinforcement	Remarks
56	12	$\frac{3}{4}$	$\frac{5}{16}$	$\frac{3}{16}$	$\frac{1}{8}$	0·44	0·76	—0·04	Groove not filled
57	,,	$\frac{1}{2}$	,,	,,	,,	0·40	0·80	0·10	
58	6	$\frac{3}{4}$	$\frac{7}{16}$	$\frac{1}{16}$	,,	0·50	1·25	0·14	Backhand (10° slope)

the shielding gas was pure argon. The two guns were usually mounted side by side (Fig. 6); a few experiments, however, were made with the guns fore and aft. Plate for all the experimental work was $\frac{1}{2}$ in. thick hot rolled phosphorus-deoxidised copper.

One series of experiments was designed to investigate the effect of the spacing of the two electrodes on weld shape, penetration, and reinforcement. For this purpose, bead-on-plate tests were performed with the wires separated by a distance of from zero to one inch. Penetration measurements on the sectioned, polished, and etched beads are contained in Table V and a few of the beads are illustrated in Fig. 7.

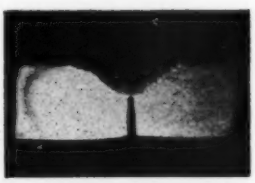
The effect of chamfering the edges of the plates at various angles was investigated in welding from one side. In every case the root face was $\frac{1}{4}$ in. and the angle cut on each pair of plates was 5, 15, 25, 35, or 45°, giving included angles of 10, 30, 50, 70, and 90° respectively. Details are recorded in Table VI and typical welds are shown in Fig. 8.

In view of the poor penetration obtained when welding chamfered plates, the applicability of a U preparation was investigated under the conditions detailed in Table VII, typical sections being illustrated in Fig. 9. It was difficult to fill the prepared groove with weld metal in one run with the guns in the forehand position, and an attempt was made to weld in one pass by the backhand technique. During backhand welding, it was noted that a considerable amount of molten metal ran along the root of the groove, but subsequent examination revealed that this metal was fully incorporated in the weld (Fig. 10).

Discussion of results

As will be seen from examination of Fig. 6, which shows the arrangement of the welding guns, the point of contact of the two electrode wires could be made to coincide with the surface of the plates or, if desired, to meet at a predetermined depth below the plate surface. With the wires separated by 1 in. (weld 50 of Table V and Fig. 7*g*) the two wires burned as individual electrodes and formed two separate beads. At $\frac{3}{4}$ in. separation (weld 49 of Table V and Fig. 7*f*) two separate beads were deposited at the start of the weld and these ran together, as the temperature of the plate increased by arc heating, to form one bead with two distinct tongues of penetration. When the separation was decreased further, the two wires formed one bead which was generally free from defects even though the welding current was 400 amp on each wire. One instance of tunnelling was observed in weld 45 of Table V (Fig. 7*b*). However, this fault was eliminated and penetration improved by increasing the welding speed and raising the electrodes (Fig. 7*c*).

A few *ad hoc* trial welds were made with square edge close butted plates (Fig. 11), and it was apparent that welds could be made in two runs, one from each side of the plate, if the process of back chipping and sealing were to be adopted. However, the amount of metal to be removed was thought to be excessive, and some kind of weld preparation was considered to be desirable.



11—*Two-wire square edge close butt weld*

In the single-V butt welding trials (Table VI and Fig. 8), the best results were obtained with the 70° included angle, but in every instance defect-free welds were obtained with excellent interfusion between weld metal and parent metal.

It was apparent that in the welds made with single-U preparations (Table VII), with a groove $\frac{5}{16}$ in. deep and $\frac{3}{4}$ in. wide, the amount of deposited metal was insufficient, and better joint filling was obtained with a groove of the same depth but only $\frac{1}{2}$ in. wide. However, by means of the backhand welding method, filling of a $\frac{3}{4}$ in. wide groove $\frac{7}{16}$ in. deep was accomplished, with the results illustrated in Fig. 10.

One of the shortcomings of the use of existing commercial welding equipment in this investigation has been the difficulty of bringing the electrode wires close together. Thus it was only safe to infer from examination of the two-wire bead-on-plate macrosections (Figs. 7–11) that the optimum electrode separation was of the order of $\frac{3}{8}$ in.

It is considered that significant advantages would be obtainable from a welding gun capable of feeding two or more parallel wires, with facilities for translatory movement of the wires. With such equipment a more critical appraisal of two-wire consumable electrode welding could be made.

Conclusions

The use of argon–nitrogen mixtures rather than pure argon can be beneficial in the welding of thick phosphorus-deoxidised copper by enabling preheat temperatures to be reduced or welding speeds increased. There is also a slight economic benefit in reduced shielding gas costs. Preheat cannot be eliminated entirely owing to the form of the molten pool and the risk of tunnelling with $\frac{1}{16}$ in. dia. wire at currents of the order of 400 amp and above. It is possible that high current welding with larger diameter wire would be satisfactory, but power sources of considerably greater output than those commonly available would be required to weld metal of $\frac{1}{2}$ in. thickness and above.

The twin consumable electrode process is probably more versatile and could tackle a wide range of material thicknesses using commercially available power sources of 400–500 amp capacity. Its application to the downhand welding of $\frac{1}{2}$ in. thick unpreheated copper has been demonstrated although its suitability for positional welding is in doubt owing to the size of the molten pool. Clearly the twin-electrode process with argon–nitrogen shielding should be economically attractive, but further advances would depend on the availability of suitable twin-electrode equipment.

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Meeting in Utrecht (see p. 366)

Right: *The Mayor of Utrecht speaking to J. C. Beugelink (on his right), Secretary of the Netherlands Welding Society. Mr. W. P. Kerkhof, President of the Society is on the Mayor's left, and Mr. G. Parsloe, Secretary of the British Institute of Welding is on the extreme left of the picture.*

Below: *Professor G. Westendorp (left) and Mr. S. R. Banks (right) presenting their papers at the technical sessions.*

B.W.R.A. REPORT

Investigation of Filler Materials for Welding Al–Zn–Mg Alloys

By P. T. Houldcroft, B.SC.

The report describes work carried out mainly during the period 1953–56 with the object of devising a filler material for welding high-strength Al–Zn–Mg alloys of the type used in the British aircraft industry to specification DTD 683. The aim was to produce a filler alloy which would give weld metal of sufficiently good resistance to cracking to be reliable under all but the most severe welding conditions, and to possess a strength high enough to ensure yielding in the softened heat-affected zone before failure of the joint.

The preparation of filler rods of various compositions shows that almost any variation in the Zn and Mg contents alone does not give the required resistance to cracking. The addition of limited amounts of silicon to the filler material to reduce the solidus temperature gave some improvement in resistance to cracking. Additions sufficient for adequate cracking resistance, however, adversely affected joint strength.

The work suggested that it was impossible to devise a completely satisfactory filler alloy for the high-strength Al–Zn–Mg alloys, but that there might be scope with alloys of lower alloy content including the medium-strength Al–Zn–Mg alloys used on the Continent.

A PREVIOUS report[1] described work on the development of filler alloys for welding the high-strength heat-treatable Al–Cu–Mg alloys. The general approach was to develop a filler alloy which would give weld metal of sufficiently good resistance to cracking to be reliable under all but the most severe welding conditions, together with a strength high enough to ensure yielding in the softened heat-affected zone before failure of the joint. The investigation involved the use of a specially developed cracking test, mechanical tests on welded joints, and ageing tests on as-deposited weld metal. Alloys in the Al–Cu–Mg–Si system were examined for suitability as filler materials, an initial selection being made on the basis of the work on cracking of the welding research team at Birmingham University[2] and B.W.R.A. work on the dilution of weld beads.[3]

The present report describes work, carried out on similar lines, with the object of devising a filler material for welding the high-strength Al–Zn–Mg alloys, containing a nominal 6% Zn, 2·75% Mg, as used in the British aircraft industry to the specification DTD 683.

Selection of Alloys for Test

When the work began (in 1953) data on the cracking tendencies of Al–Zn–Mg alloys were sparse. It was known in general terms, however, from welds made in DTD 683 with Al–Mg fillers, that filler alloys high in magnesium gave welds less susceptible to cracking than the parent material. There was also evidence that copper had an adverse effect.[4] The initial selection of filler alloys for testing was made therefore mainly on the basis of mechanical properties.

Hardness surveys of welds in DTD 683 indicated that the minimum hardness in the heat-affected zone was not likely to be much more than 110–120 D.P.N. Tests on samples of parent plate, over-aged at 250°C., the temperature likely to be attained in the heat-affected zone, showed that a hardness of 110–120 D.P.N. corresponded with a proof stress of about 18–20 tons/sq.in. and an ultimate stress of 24–26 tons/sq.in. As for welds in Al–Cu–Mg alloys the limit or joint strength was imposed not by the softening in the heat-affected zone but by the strength of the weld metal. To fulfil the requirement that yielding or failure should occur in this region and not in the weld metal, it was clearly essential to select filler alloys capable of giving the highest possible strength in the weld bead.

The effect of composition on the properties of wrought and cast Al–Zn–Mg alloys has received considerable attention. Recent work on wrought alloys, including that by Herenguel,[5] and Cook,

Report C2/4/58 of the British Welding Research Association, circulated to members in November 1959.
Mr. Houldcroft is Chief Metallurgist of the Association.

Chadwick, and Muir,[6] indicated that the compositions of wrought alloys of equal strength lay on roughly hyperbolic lines in the Al–Zn–Mg ternary diagram, the lines being closer together at the zinc end. Above a Zn+Mg content of 9% excessive brittleness was reported.

A useful range of casting alloys, investigated by Eastwood and Kempf,[7] and also by Holzworth,[8] contained 0·5–0·75% Mg and up to 8% Zn. The strength of these alloys in the sand-cast condition increased progressively from 14 tons/sq.in. at 3% Zn to 18 tons/sq.in. at 8% Zn.

Data were also available on the properties of binary Al–Mg alloys as both chill castings and welded wrought material. These data indicated that the U.T.S. of welds was somewhat higher than that of chill castings in the same alloy. A strength of 19 tons/sq.in. was obtained in welds in an Al–7% Mg alloy, and 17 tons/sq.in. in an Al–5% Mg alloy.

In view of this, the first series of alloys for test, Series I, Table I, included several alloys with Zn+Mg of about 9% with high zinc (which were thought to promise the best strength); three alloys of near parent metal composition, two having higher magnesium contents than normal; and one alloy with high magnesium and low zinc. This last alloy was not expected to give the highest strength but it was hoped that it would give improved resistance to cracking. The effect of copper content was investigated by repeating the series with copper at about 0·5%. Subsequently a second series of alloys, Series II, Table II, was produced with rather lower Zn+Mg contents but including 0·5% Ti. In a third phase of the investigation, additions of Si were made to overcome cracking, the object being to add enough Si to prevent cracking but not enough to affect the weld strength adversely. The alloys investigated are given in Table III.

One of the difficulties in devising filler alloys for a parent metal high in alloying additions, such as DTD 683, is that the composition of the weld bead cannot be changed significantly unless either very large additions are made to the filler alloy or the dilution is kept to a low level.

Table I

Analysis of series I Al–Zn–Mg filler alloys

Filler		*Composition, %*				
No.	*Cast*	*Zn*	*Mg*	*Cu*	*Si*	*Ti*
1	545	9·07	1·1	—	0·15–0·20	0·14
2	546	8·97	1·2	0·47	,,	0·14
3	547	7·80	2·07	—	,,	0·15
4	548	7·60	2·05	0·53	,,	0·13
5	549	5·2	2·56	0·48	,,	0·14
6	552	5·55	3·05	1·50	,,	0·15
7	553	5·57	2·97	0·52	,,	0·15
8	593	5·25	3·0	—	,,	0·14
9	554	6·55	2·95	0·48	,,	0·14
10	555	4·49	3·98	—	,,	0·14
11	556	4·75	3·85	0·48	,,	0·14
12	557	4·45	5·36	—	,,	0·14
13	558	4·44	5·49	0·49	,,	0·12
14	579	6·10	2·64	1·35	,,	0·14
15	581	6·08	2·62	1·40	,,	0·14*
16	ZM26a	2·68	5·85	0·19	,,	0·15
17	ZM26b	3·00	5·98	0·19	,,	0·58
18	ZM46	4·67	6·67	0·09	,,	0·13

* Contained also 0·05% boron

All alloys contained 0·15–0·20% Fe and Nos. 1–15 contained 0·15–0·20% Cr

Table II

Analysis of series II Al–Zn–Mg filler alloys

Filler		*Composition, %*				
No.	*Cast*	*Zn*	*Mg*	*Cu*	*Si*	*Ti*
40	C17	8·60	0·50	0·46	0·15–0·20	0·28
41	C18	7·23	0·37	0·44	,,	0·68
42	C19	7·52	1·97	0·72	,,	0·62
43	C20	6·03	1·05	0·59	,,	0·42
44	C21	4·74	0·075	0·54	,,	0·72
45	C22	3·25	1·29	0·65	,,	0·72
46	C23	1·69	2·44	0·56	,,	0·28
47	C24	2·01	4·12	0·49	,,	0·50
48	C25	3·98	4·07	0·52	,,	0·37
49	C26	4·99	2·34	0·47	,,	0·44

All alloys contained a nominal 0·15% Fe, with Cr absent

Table III

Analysis of series III Al–Zn–Mg filler alloys

Filler		*Composition, %*				
No.	*Cast*	*Zn*	*Mg*	*Cu*	*Si*	*Ti*
50	C27	4·28	2·31	0·49	0·91	0·35
51	S34	5·70	1·55	—	0·62	0·20
52	S35	8·00	1·46	—	0·97	0·29
53	S36	4·40	3·64	—	0·60	0·24
54	S37	4·26	3·45	—	1·54	0·22
55	S39	5·30	2·93	—	0·81	0·28
56	S38	5·00	3·51	—	1·31	0·26
57	PMS	4·91	1·83	0·55	2·80	0·09

All alloys contained a nominal 0·15% Fe, with Cr absent

Table IV

Mechanical properties of some Al–Zn–Mg filler alloys in the extruded annealed and extruded fully heat-treated conditions

				Properties				
				Annealed		*Heat-treated*		
Nominal Analysis, %				*Elong. on* $4\sqrt{A}$,	*U.T.S.,*	*Elong. on* $4\sqrt{A}$,	*0·1% Proof Stress,*	*U.T.S.,*
No.	*Zn*	*Mg*	*Cu*	*%*	*tons/sq.in*	*%*	*tons/sq.in.*	*tons/sq.in*
1	9	1	—	25	20·0	20	23·0	29·0
2	9	1	0·5	20	19·8	20	29·0	33·0
3	7·5	2	—	25	16·3	15	33·5	36·0
4	7·5	2	0·5	20	17·3	15	35·0	38·0
9	6·5	3	0·5	20	17·5	15	36·0	41·0
12	4·5	5·5	—	17	21·3	15	28·0	34·3
13	4·5	5·5	0·5	17	20·5	15	30·5	35·0

Experimental Techniques

Filler rod preparation

Series I alloys were chill cast to 1 in. dia. ingots and extruded to $\frac{1}{4}$ in. dia. rod on an extrusion press fitted to a 50 ton testing machine. These rods were drawn to wire to $\frac{3}{32}$ and $\frac{1}{8}$ in. dia., degreased, and pickled. As a matter of interest, the mechanical properties of several of the extruded rods were determined in the annealed and solution heat-treated conditions (Table IV).

Series II alloys were cast as $\frac{1}{8}$ in. thick plates from which the filler rods were cut as strips. To make handling of the filler rod easier during welding, the edges of the strips were rounded by grinding so that the finished rod was roughly $\frac{3}{32}$ in. dia. The rods were degreased and pickled before use.

Series III alloys were prepared by both these methods.

Filler alloy assessment

The same procedure was adopted as for the work on Al–Cu–Mg alloys[1]—briefly: cracking tests using the specially developed 'fishbone' cracking tests;[9] ageing tests on as-deposited weld metal; and mechanical tests on welds in $\frac{1}{8}$ in. and $\frac{1}{4}$ in. thick material made by the argon tungsten-arc process. Work on weld metal ageing in relation to filler alloy selection for both the Al–Cu–Mg and Al–Zn–Mg alloys has been fully reported previously.

Cracking tests were made on 0·063 in. thick material using $\frac{3}{32}$ in. dia. filler and argon tungsten-arc welding with a current of 65 amp. The dilution in the cracking tests was 65–75%.

Welds in $\frac{1}{8}$ in. thick material were made by manual argonarc welding at 165 amp and 10 in./min using $\frac{1}{8}$ in. dia. filler and a close square butt edge preparation, which gave a weld dilution of about 70%. For welds in $\frac{1}{4}$ in. thick plate the current was 250 amp and a single pass, 70% single-V technique was used giving a welding speed of 4 in./min and a dilution of 40–50%. In welds made using the cast filler rods it was difficult to avoid oxide inclusions completely, and a number of test pieces had to be discarded. Cracking also occurred in a number of test plates.

Weld Cracking

Cracking tests on all the alloys investigated are summarised in Tables V and VI. The results are reported as the length of cracking in inches—the longer the crack the more severe is the cracking tendency. A crack length of less than 0·5 in. is regarded as indicating that the alloy would be trouble-free in practice.

The main impression of the results of the Series I tests was that cracking was little affected by even large variations in the Zn and Mg content of the filler material. This was thought to be due to either or both of the following reasons: (*a*) dilution, accentuated by the fact that the parent alloy already contained large additions of Zn and Mg; (*b*) in the region of the Al–Zn–Mg system examined, Zn and Mg variations have little effect on cracking. It was clear that there was no point in employing copper-free filler alloys unless copper-free parent metal was also used. The only significant improvement in cracking resistance was obtained with the alloys with over 5% Mg and additional grain refinement. None of the alloys, however, approached the 0·5 in. cracking estimated as the minimum necessary to ensure freedom from cracking in practice. The performance of filler 581 containing boron was particularly disappointing.

A further series of alloys, Series II, Table II, was then prepared from small melts using the cast slab technique. These alloys were chosen to give a generally greater variation in Zn and Mg in the weld bead than the previous series. The Cu content was maintained at 0·5% and a nominal addition of 0·5% Ti was also made to each alloy. With this second series, numbers 40–49 in Table VI, there was a barely significant overall improvement in the tests; again all the results were somewhat similar except that this time the 5% Zn alloys appeared to be a little superior. It was concluded at this stage that variations in Zn and Mg, or grain refinement, alone could not give the required improvement in cracking resistance but that there was slightly reduced cracking when using a filler alloy

Table V

Cracking tendencies of series I filler alloys

	Filler Alloy Type						*Cracking Severity**	
No.	*Zn, %*	*Mg, %*	*Cu, %*	*Si, %*	*Ti, %*	*No. of Tests*	*Centre Length†*	*No.‡*
1	9	1	—	—	0·15	6	1·39	6
2	9	1	0·5	—	,,	6	1·13	6
3	7·5	2	—	—	,,	6	1·18	6
4	7·5	2	0·5	—	,,	6	1·20	6
5	5	2·5	0·5	—	,,	6	1·28	6
6	5·5	3	1·5	—	,,	7	1·3	7
7	5·5	3	0·5	—	,,	6	1·28§	6
8	5·5	3	—	—	,,	7	1·57	7
9	6·5	3	0·5	—	,,	6	1·18§	6
10	4·5	4	—	—	,,	6	1·16§	6
11	4·5	4	0·5	—	,,	6	1·08	6
13	4·5	5·5	0·5	—	,,	6	0·89§	6
14	6	2·5	1·5	—	,,	6	1·48	6
15	6	2·5	1·5	—	+B	6	1·42	6
16	2	6	—	—	0·15	6	1·11	6
17	2	6	—	—	0·50	6	0·80	6
18	4	6	—	—	0·15	6	0·91	6

* There was no edge cracking
† Average length of crack in samples exhibiting the type of cracking noted
‡ Number of samples exhibiting the type of cracking noted
§ Parent metal cracks also in these tests.
Parent metal analysis: Zn, 6·27%; Mg, 3·1%; Cu, 1·36%; Mn, 0·4%

Table VI

Cracking tendencies of series II and III filler alloys

	Filler Alloy Type					*No.*	*Cracking Severity*			
	Zn,	*Mg,*	*Cu,*	*Si,*	*Ti,*	*of*	*Centre*		*Edge*	
No.	*%*	*%*	*%*	*%*	*%*	*Tests*	*Length*	*No.*	*Length*	*No.*
40	8·5	0·5	0·5	—	0·5	8	1·30	7	1·40	1
41	7	0·5	,,	—	,,	6	1·38	6	—	—
42	7·5	2	,,	—	,,	6	1·10	6	—	—
43	6	1	,,	—	,,	6	1·50	5	1·40	1
44	5	—	,,	—	,,	6	1·03	6	—	—
45	3·25	1·25	,,	—	,,	6	1·19	6	—	—
46	1·5	2·5	,,	—	,,	6	1·17	6	—	—
47	2	4	,,	—	,,	9	1·12	8	1·40	1
48	4	4	,,	—	,,	6	1·07	6	—	—
49	5	2·5	,,	—	,,	7	1·00	7	—	—
50	4	2·5	0·5	1	0·5	8	0·72	8	0·90	4
51	6	1·5	—	0·5	0·25	6	0·84	6	0·54	3
52	8	1·5	—	1	,,	5	1·10	5	0·57	2
53	4·5	3·5	—	0·5	,,	6	1·09	6	—	—
54	4·5	3·5	—	1·5	,,	5	0·27	4	1·63*	5
55	5	3	—	1	,,	5	0·82	4	1·45	2
56	5	3	—	1·5	,,	5	0·93	4	1·32	2
57	5	2	0·5	2·5	—	6	0·35	6	—	—

* Cracks in parent material

with 5% Zn and up to 2% Mg or an alloy with 4% Zn and 4–6% Mg.

Patterson, Kümmerle and Lessenich[11] have reported a complex cracking diagram for Al–Zn–Mg alloys with 0·5% Cu, based on ring-casting tests. A small region of reduced crack sensitivity was observed at about 6% Zn and low magnesium and another larger area at about 4·5–8·5% Zn and 5–6% Mg.

These observations are not at variance with the weld cracking tests reported here if allowance is made for dilution.

It was known that there was freedom from cracking in welds made with an Al–5% Si filler rod but that the weld beads so produced were of low strength. There appeared to be a possibility, however, that silicon additions could be controlled in such a way that adequate cracking resistance could be obtained without too great a sacrifice of weld properties. Series III alloys (Table III) were then prepared with additions of from 0·5 to 2·5% Si. Because of difficulties in controlling additions of titanium at the 0·5% level this series was prepared with a nominal 0·2% Ti.

It was apparent from the results with fillers 50–56 in Table VI, that additions of 1·5% Si were not sufficient to reduce cracking to the required level. The incidence of edge cracking was also noticeably increased. This in itself is not unsatisfactory, however, for the first stage in the prevention of cracking is to move the position of the crack from the weld bead to the edge of the weld. To prevent cracking entirely it is necessary to improve both the cracking resistance of the weld bead and also to lower its solidus so that the parent metal is locally unstressed when passing through its hot-short range. An addition of 2·5% nominal (2·8% actual) Si to the best alloy in Series II, with the object of reducing the solidus of the weld bead, reduced cracking to well below the required level (test No. 57) but it was evident from the margin of safety that the addition was excessive.

If any further work is done on devising filler alloys for DTD 683 or other Al–Zn–Mg alloys it would be worth considering two alloys; 5% Zn–2% Mg and 4% Zn–5% Mg, each with 1–2% Si. Preference might be given to the former composition since a high-zinc–high-magnesium alloy would be difficult to draw to wire and would be more suspect as regards stress corrosion.

Table VII

U.T.S. of welds in 1/8 in. thick DTD 683 made with some of series I alloys

Filler No.	Filler Type Zn, %	Mg, %	Cu, %	U.T.S., tons/sq.in. As-welded*	Reheat-treated	Weld Analysis† Zn, %	Mg, %	Cu, %
1	9	1	—	21·8	36·5	6·7	1·91	1·02
2	9	1	0·5	22·2	31·0	6·8	2·24	1·19
3	7·5	2	—	22·3	34·4	6·5	2·44	1·08
4	7·5	2	0·5	21·2	33·8	6·4	2·40	1·15
9	6·5	3	0·5	22·8	36·4	6·2	2·65	1·18
12	4·5	5·5	—	20·6	33·8	5·6	3·31	1·03
13	4·5	5·5	0·5	23·0	35·6	5·4	3·52	1·10
15	6	2·5	1·5	22·9	36·3	6·0	2·57	1·41

Parent metal analysis: Zn. 6·01%; Mg, 2·55%; Cu, 1·41%; Mn, 0·27%.
U.T.S. of parent metal = 38·3 tons/sq.in.
Location of fracture in the as-welded conditions was frequently in the weld metal unless the U.T.S. exceeded 22 tons/sq.in., when it generally occurred at the edge of the weld. After heat treatment weld metal failures did not occur where the U.T.S. exceeded 35 tons/sq.in.
* Aged 2–4 weeks
† Estimated from dilution at approx. 70%

Table VIII

U.T.S. of welds in 1/4 in. thick DTD 683 made with series I alloys

Filler No.	Filler Type Zn, %	Mg, %	Cu, %	U.T.S., tons/sq.in. As-welded*	Reheat-treated	Weld Analysis† Zn, %	Mg, %	Cu, %
1	9	1	—	20·1	33·2	7·7	1·9	0·2
2	9	1	0·5	21·9	34·6	7·5	2·0	0·5
3	7·5	2	—	25·0	37·9	6·7	2·5	0·3
4	7·5	2	0·5	24·7	35·4	6·7	2·5	0·5
5	5	2·5	0·5	22·2	33·6	5·4	2·7	0·5
6	5·5	3	1·5	22·6	35·3	5·6	3·0	1·0
7	5·5	3	0·5	19·6	34·2	5·6	3·0	0·5
9	6·5	3	0·5	23·9	34·6	6·2	3·0	0·5
10	4·5	4	—	23·9	33·5	5·1	3·5	0·2
11	4·5	4	0·5	22·5	35·8	5·2	3·4	0·5
12	4·5	5·5	—	22·7	35·6	5·1	4·2	0·2
13	4·5	5·5	0·5	23·2	35·8	5·1	4·2	0·5
14	6	2·5	1·5	26·6	36·0	6·0	2·8	0·8

Parent metal analysis: Zn, 6·03%; Mg, 2·7%; Cu, 0·51%; Mn, 0·32%.
Properties of parent metal: Proof stress 31·9; U.T.S. 38·2 tons/sq.in; Elong. 12%.
Location of fracture in the as-welded condition was at the edge of the weld except with filler 14 when it was in the heat-affected zone. Failure after reheat-treatment was almost always in the weld metal.
* Aged 4–6 weeks
† Estimated from dilution at approx. 45%

Joint Strength

The properties of joints in $\frac{1}{8}$ in. and $\frac{1}{4}$ in. material made with most of the filler alloys used in the cracking investigations were examined by tensile testing joints with the weld reinforcement removed.

As shown in Table VII, the U.T.S. in both the as-welded and reheat-treated $\frac{1}{8}$ in. thick material was fairly consistent, regardless of the filler material. This was to be expected, for the dilution was high and the estimated weld bead compositions were similar. With welds in $\frac{1}{4}$ in. plate (Table VIII) rather higher properties were obtained, the best results being with the parent metal filler. When these first tests were made it was not appreciated that weld beads of this composition would be so readily susceptible to natural ageing and no special precautions were taken to control the time lapse between welding and testing. The slightly lower figures for $\frac{1}{8}$ in. material may have been due to a shorter ageing period.

Tables IX and X giving the U.T.S. of joints made with some of the Si-containing filler alloys, indicate that when joints received an artificial ageing treatment the addition of Si had little effect on properties. When the hardness in the weld bead exceeded that in the heat-affected zone by a factor of $\geqslant 1{\cdot}3$, the location of fracture moved to the heat-affected zone. As with the welds in DTD 646 reported previously, there was a tendency in transverse tensile testing towards failure

at the edge of the weld in the overheated fusion zone where porosity had developed. This mode of failure has been attributed to the gas content of the parent metal.[1]

Mechanical properties of welds in $\frac{1}{8}$ in. sheet made by the only filler alloy giving adequate crack resistance (No. 57) were considerably lower than for any of the other alloys (Table XI). Whilst some improvement on these results might be obtained by minor adjustment of the filler composition it is clear that joint efficiencies above 60% will be difficult to obtain.

Although there are a number of gaps in the work reported, there is little doubt that adequate crack resistance as well as reasonable weld strength cannot be obtained from the same filler alloy. If some susceptibility to cracking can be tolerated, however, there are several filler alloys which would give an as-welded U.T.S. of about 24 tons/sq.in., corresponding to a 65% joint efficiency.

A change in parent metal composition to a lower total Zn and Mg alloy content might enable the required cracking resistance to be obtained without

Table IX

Mechanical properties of welds in 1/8 in. DTD 683 made with some series I and series III filler alloys

	*Weld Analysis**				*U.T.S.,*	*Elong. on 2 in.,*		*Fracture‡*		
Filler No.	*Zn, %*	*Mg, %*	*Cu, %*	*Si, %*	*tons/sq.in.*	*%*	H_u †	*Weld*	*Edge*	*Plate*
(*a*)										
18	5·6	3·9	0·9	0·2	34·3	4·0	1·0	—	6	—
16	4·4	3·6	1·0	0·2	33·3	3·5	0·97	2	3	—
52	6·6	2·2	0·9	0·45	32·1	2·0	1·03	3	2	—
53	5·5	2·8	0·9	0·3	34·0	3·0	0·98	1	3	—
54	5·4	2·8	0·9	0·6	30·9	2·0	0·96	1	3	—
(*b*)										
18	5·6	3·9	0·9	0·2	21·3	2·5	0·87	1	2	—
16	4·4	3·6	1·0	0·2	21·4	2·0	0·89	1	—	—
52	6·6	2·2	0·9	0·45	24·4	2·0	0·89	1	—	—
53	5·5	2·8	0·9	0·3	25·4	3·0	0·9	—	1	—
54	5·4	2·8	0·9	0·6	20·7	1·3	0·9	2	2	—

(*a*) Fully heat treated after welding
(*b*) Sheet fully heat treated before welding, joints aged naturally for six weeks before testing.

* Calculated from dilution
† An indication of hardness uniformity, minimum hardness in weld metal divided by minimum hardness in heat-affected zone (*see* ref. 1). Weld metal softer than HAZ when H_u less than 1 and vice versa.
‡ Figures give number of tests which failed in the manner indicated
Parent metal analysis: Zn, 6·01%, Mg, 2·55%; Cu, 1·41%; Cr, 0·12%
Properties of parent metal: Proof stress, 32·8: U.T.S., 37·4; Elong., 11·5%

Table X

Mechanical properties of welds in 1/4 in. DTD 683 made with some series I and series III filler alloys

	*Weld Analysis**				*U.T.S.,*	*Elong. on 2 in.,*		*Fracture‡*		
Filler No.	*Zn, %*	*Mg, %*	*Cu, %*	*Si, %*	*tons/sq.in.*	*%*	H_u †	*Weld*	*Edge*	*Plate*
(*a*)										
18	5·4	4·9	0·25	0·2	32·7	1·75	0·93	—	6	—
16	5·1	4·4	0·35	0·2	33·1	2·5	0·91	2	4	—
17	5·0	4·5	0·35	0·2	32·7	1·3	1·02	1	1	—
52	7·0	2·0	0·25	0·6	30·3	1·5	0·89	—	6	—
53	5·1	3·2	0·25	0·4	33·0	2·0	0·95	1	7	—
54	5·0	3·1	0·25	0·5	29·8	1·0	0·87	2	1	—
(*b*)										
18	5·4	4·9	0·25	0·2	20·8	2·5	0·99	—	3	—
16	5·1	4·4	0·35	0·2	23·7	4·0	0·97	—	3	—
17	5·0	4·5	0·35	0·2	21·6	4·0	1·31	—	2	—
52	7·0	2·0	0·25	0·6	21·3	1·5	1·06	—	3	—
53	5·1	3·2	0·25	0·4	21·3	2·5	1·13	—	3	—
(*c*)										
18	5·4	4·9	0·25	0·2	23·7	2·5	1·25	2	2	—
16	5·1	4·4	0·35	0·2	23·5	4·0	0·97	2	6	—
52	7·0	2·0	0·25	0·6	23·8	4·0	1·49	1	2	2
53	5·1	3·2	0·25	0·4	24·9	6·0	1·4	—	1	4
54	5·0	3·1	0·25	0·9	24·2	2·5	1·26	—	4	1

(*a*) Fully heat treated after welding
(*b*) Joints aged for 6 weeks after welding
(*c*) Plate welded in solution heat-treated condition, joints aged for 10 hr at 135°C.

* Calculated from dilution
† An indication of hardness uniformity, minimum hardness in weld metal divided by minimum hardness in heat-affected zone
‡ (*see* ref. 1). Weld metal softer than HAZ when H_u less than 1 and vice versa.
Figures give number of tests which failed in the manner indicated.

Table XI

Properties of welds in 1/8 in DTD 683 made with high silicon filler No. 57

Condition	Weld Analysis* Zn, %	Mg, %	Cu, %	Si, %	U.T.S., tons/sq.in.	Elong. on 2 in., %	H_u †	Fracture Weld	Edge	Plate
AW	5·7	2·3	1·1	1·2	18·5	2	0·93	6	—	—
WA	5·7	2·3	1·1	1·2	21·9	2·5	1·15	6	—	—
FT	5·7	2·3	1·1	1·2	20·2	1·5	0·65	3	—	—

AW = As-welded
WA = As-welded and aged at 140° for 10 hr
FT = Fully heat-treated after welding

* Calculated from dilution

† An indication of hardness uniformity, minimum hardness in weld metal divided by minimum hardness in heat-affected zone (*see* ref. 1). Weld Metal softer than HAZ when H_u less than 1 and vice versa.

much sacrifice of welded joint strength, although the strength of the parent metal would undoubtedly be lower than that of DTD 683. If a joint efficiency of about 75% is considered to be adequate it might be possible to find a suitable filler alloy for a parent metal at the low end of the DTD 683 specification. A parent metal of this type would, however, have to be treated as virtually a new alloy.

Much of the experience gained in the present work could be applied to the alloys with lower Zn and Mg contents being produced at present on the Continent. These alloys have the property of ageing naturally in the heat-affected zone after welding, so that the joints approach 100% efficiency. The strength of these alloys in wrought form, however, is considerably lower than that of DTD 683.

Conclusions

It has not been possible, by varying only the Zn and Mg contents, to devise a filler material for welding DTD 683, which will give the required resistance to cracking. The fact that little change in cracking tendencies resulted from quite large variations in filler composition is thought to be due to the effect of dilution, and also because, in the region of weld metal compositions covered by the variations, the cracking tendencies of Al–Zn–Mg alloys are similar. Adequate cracking resistance can be obtained by reducing the solidus of the weld bead with the introduction of silicon. Successful welds have been made with an alloy containing 5% Zn–2% Mg and 2·5% Si.

With several filler alloys, including a parent metal filler, an as-welded joint strength of about 25 tons/sq.in. U.T.S. has been obtained, with failure frequently in the heat-affected zone. The addition of sufficient Si to give adequate resistance to cracking, however, prevents this strength from being obtained, although about 20 tons/sq.in. U.T.S. can be achieved.

For a parent metal of lower total alloy content, it may be possible to develop a filler alloy with the required resistance to cracking without such a serious sacrifice of joint strength, and actually to obtain higher joint efficiencies.

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Annual General Meeting

The Thirty-Eighth Annual General Meeting of the Institute will be held at 54 Princes Gate, Exhibition Road, South Kensington, London, S.W.7, on Thursday, 13th July, 1961 at 2.30 p.m.

Honorary Officers for 1961–2

The following members, nominated by the Council, have been elected unopposed, and will take office at the Annual General Meeting, on 13th July, 1961:

President: Mr. H. West

Vice-Presidents: Mr. C. Humphrey Davy
Mr. L. Redshaw

Honorary Treasurer: Mr W. E. Harriss.

Joint meeting with the Netherlands Welding Society

Nearly 40 members of the Institute of Welding, together with visitors from Belgium, France, Germany, Switzerland, and the U.S.A., enjoyed the hospitality of their Dutch colleagues for three days at the beginning of June. The occasion was a Joint Meeting of the Netherlands Welding Society (Nederlandse Vereniging voor Lastechniek) and the British Institute of Welding to discuss papers on the theme of 'Aluminium'.

Participants were received and welcomed to the Congress Hall in Utrecht on the morning of 31st May by ir.W. P. Kerkhof, President of the Netherlands Welding Society, who also presided at the first session for the presentation of papers.

These were on the subject of 'Weldability' as follows:

"*Some remarks on the weldability of aluminium*" by Prof. ir. G. Westendorp

"*Factors influencing the properties of welds in aluminium*" by J. C. Bailey and G. W. Eldridge

In the afternoon, at the 2nd session under the chairmanship of Mr. J. C. Bailey in the regrettable absence of the President, Mr. Edgar Fuchs, two papers were presented on the subject "Construction":

"*Some notes on the design of chemical equipment in aluminium*" by Prof. ir. F. C. A. A. van Berkel and Prof. ir. E. F. Boon

"*Some design considerations for welded aluminium*" by S. R. Banks and R. E. Smith

The proceedings for the whole of the meeting were conducted in English, and the Dutch speakers are to be congratulated for their excellent delivery of summaries of their papers and the clarity of their replies to questions.

The afternoon's discussion had to close early to allow participants to go to the Town Hall, Utrecht, where they were officially received by the Mayor in the candle-lit Reception Chamber.

The Mayor recounted briefly some of the early history of Utrecht but also referred to its modern industry and particularly to the Royal Netherlands Industries Fair, which was presently the venue of the Welding Exhibition 'Lastu 61'. He welcomed the British and other visitors and hoped that their interchange of views with their Dutch colleagues would be fruitful.

Mr. Kerkhof, President of the Netherlands Welding Society, and Mr. G. Parsloe, Secretary of the British Institute of Welding responded with brief speeches.

The technical sessions resumed on Thursday morning, 1st June, with discussions on the subject "Welding", presented in three papers:

"*Aluminium welding practice*" by L. Capel

"*Development of Mig welding techniques for aluminium*" by J. E. Tomlinson and D. Slater

"*A recent specification for fusion welded aluminium and aluminium alloy pressure vessels for Class I duties*" by F. Smith.

The Chairman was Prof. ir. C. A. A. v.d. Woude, Director of the Netherlands Centre for Welding Technique.

On Thursday afternoon visitors were free to tour the Welding Exhibition in the adjacent hall. Exhibits were international and represented most of the welding processes. The British visitors appeared to be most interested in the variety of submerged-arc units and CO_2 equipment. It is certain that many interesting views were exchanged with the representatives on the various stands.

The evening was the occasion for an informal dinner which will be long remembered by the British guests of the Netherlands Welding Society. It was held in the Kurhaus at the seaside resort of Scheveningen, near The Hague.

This was a thoroughly enjoyable occasion when members were able to meet their Dutch colleagues informally and to enjoy to the full Dutch hospitality.

The more serious part of the evening —the dinner—was prefaced by brief humorous speeches by Mr. Kerkhof and Mr. Parsloe.

On the return to Utrecht by coach a tour was made of the promenade road of Scheveningen which enabled visitors to see the newly constructed pier in a blaze of lights.

The last day of the meeting, Friday, 2nd June, was devoted to tours of the Amsterdam and Utrecht works of Werkspoor N.V. At Amsterdam, where the original works was started on the site of the old Dutch East India Company, the manufacture and assembly of all sizes of diesel engines and rolling stock was examined with great interest. There was particular comment on the well equipped machine shops and the evident skill of the craftsmen. The also well-equipped training school was a focus of special interest.

Although there were no large aluminium constructions in course of fabrication, visitors were impressed with the work on large pressure vessels and similar constructions at the Utrecht works. Differences in assembly techniques and welding procedures were discussed with the guides and much useful information was exchanged.

The Dutch hosts are to be congratulated on the organisation of a most useful and interesting joint meeting and

are warmly thanked for their hospitality and friendliness to their British guests.

The following summing-up of the technical proceedings was presented by the Chairman at the end of the final session.

Summary by Prof. ir. C. A. A. v.d. Woude

In trying to summarise the discussions of this Joint Meeting, I have found it rather difficult to make a reasonable account from my notes; more so on this morning's session with the many, many questions that were asked.

The fact that a weld in some aluminium materials is always assumed to have a reduced strength was explained in the first paper on the basis of our metallurgical knowledge. To decrease the detrimental effect on strength, the width of the heat-affected zone can be kept within certain limits by high welding speed or by accelerated cooling, or by both.

If the weakened zone is narrow compared with the plate thickness we learn from the mechanical considerations based on compression or tensile loading of an aluminium gasket, that the load necessary for yielding will be much higher than might be expected.

In regard to porosity of weldments in aluminium or its alloys there was some discussion on the occurrence of hydrogen as compared with the same phenomenon in steel. Based on curves representing the solubility of hydrogen in both metals it seems that, notwithstanding the extremely low solubility of hydrogen in aluminium appreciable amounts can remain in the solid phase. It was suggested that perhaps certain elements present in the aluminium metal might influence the development of gas bubbles, similar to the supposed influence of sulphur in steel. It is still very difficult to estimate exactly the hydrogen content in metals, and so it remains difficult also to study this feature.

In regard to the fact that porosity is most severe in the Mig welding process, it was pointed out that, because of the much thinner wire used for this welding method, the wire surface as a source of hydrogen is higher than with other processes.

As was stated during the first session, it seems that, with respect to the mechanical properties, porosity is not so dangerous as would be expected at first sight. As an example, a 100% radiographically sound weld will prove to be much weaker than a weld with an appreciable amount of porosity. Of course, cracking is the cause, but that was not mentioned.

Other defects, such as lack of fusion, and the shape of the reinforcement in welding are much more dangerous, especially with dynamic loading.

Based on the experience of industrial applications accumulated in recent years, our knowledge of the sources of defects has shown reasonable advance, and has indicated that the quality level has already been raised considerably by improving a number of relevant factors such as equipment, edge preparation, welding current, gas flow, and so on. With further efforts to improve testing procedures, it may be expected that it will be possible to formulate standards for high-class welds and relevant testing methods. However, the question of allowable stresses in construction has not yet been solved. For the time being it will be safe to keep to the criterion of 2/3 the proof stress, based on the weakest region in construction. It is therefore recommended that in the design stage welds should be avoided in highly stressed regions.

Returning to the necessity of avoiding dangerous defects it was stated again that in welding, the human eye, and I should also say the human hand, of the man behind the mask are our final and perhaps most important weapons in an endeavour to improve weld quality in aluminium and its alloys.

Coming to design, emphasis was laid on the fitness of aluminium materials for low-temperature service, and also for their resistance to corrosive influences. The main points of the discussion were price and strength parameters, in comparing aluminium with mild steel and stainless steel, and concerning the properties of the different aluminium alloys as constructional materials, with respect to corrosion and especially stress corrosion. It appeared that, regarding the price parameter, perhaps several factors, such as the geometry of the construction and the plate thickness, were not fully accounted for in the quoted formulae.

Concerning allowable stresses, we saw that because of the low Young's Modulus peak stresses are also comparatively low. And in comparing soft and hard qualities, the yield is lower for the soft material and allowable stresses would therefore be chosen lower if plastic deformation is to be avoided. It should be kept in mind in the meantime that plastic deformation results in strengthening of the material. The sensitivity of Al–Mg and Al–Zn–Mg alloys were discussed; it was pointed out that no special corrosion was experienced in tropical regions and that the Al–Zn–Mg was not notably sensitive to stress corrosion.

In ship-building, unprotected Al–Mg constructions did not show serious corrosion after several years of service, even where dissimilar aluminium materials were joined.

Corrosion does occur in the Si-bearing alloys, but not comparable with the rusting of unprotected steel under the same conditions. Whether or not the influence of silicon as an alloying element on the resistance to sea-water corrosion for aluminium is comparable with its influence in the case of steel could not be answered.

Relating to the proposition of using aluminium gaskets and practical experiences of leakage, it was pointed out that of course the efficiency of an aluminium gasket depends entirely on its deformation. At approximately 50% deformation no leakage will occur, not even if there are expansion differentials due to some temperature cycle, for instance, between two bolted flanges.

From my point of view, I feel quite happy that some remarks were made about the importance of close co-operation between the designer and the welding shop. This point was stressed too in this morning's session.

I am on very 'thin ice' in dealing with the discussions at this last session because of the multitude of questions and answers exchanged. In regard to edge preparation we have seen the differences between Tig and Mig welding and furthermore, we have received particular information on matters such as the influence of continuous current control and very recently produced apparatus for arc stabilisation.

Attention has been drawn several times to difficulties in radiographic control. There are defects which are very easily detected, such as porosity which is not dangerous, but fine defects, such as lack of penetration, and so on, are very difficult to detect, and therefore in these instances radiography is not so efficient.

At this stage I do not think that I can make any further useful remarks on these discussions.

Now that we are at the end of this meeting I would like to express our thanks, on behalf of the Netherlands Welding Society, for your kind co-operation: Firstly, to the authors for preparing the papers; secondly, to those who gave their contributions in discussions and questions; and thirdly, to all who attended the meeting.

You, who came over from England, are right cordially thanked for coming. We hope that you enjoyed the meeting. Finally, I express our appreciation to all those who came from Belgium, France and other countries abroad.

LIBRARIAN

Dr. E. M. Sinclair, librarian of the Institute since September last, has resigned her appointment and left at the end of June.

PUBLICATIONS

Radiographic Handbook

The Institute has just published on behalf of the International Institute of Welding the English edition of the "*Handbook on Radiographic Apparatus and Techniques*". This book represents

the views of the leading experts on this subject and deals briefly and simply with the apparatus and techniques for the radiographic inspection of welds, and with the precautions necessary to ensure the safety of operators. Copies may be had from the Institute of Welding, price 16s. inclusive of postage.

NEWS OF MEMBERS

Mr. T. M. B. Sessions, B.Sc., Past-Chairman of the South Western Branch of the Institute, has resigned his appointment with Messrs. Fielding and Platt Ltd., Gloucester, to join the Midland Cold Forming Alliance, Saltley, Birmingham.

Obituary

The Council regrets to record the deaths of the following Members:

Mr. J. W. Bagnall (Wolverhampton, Assoc. Member, 1944)

Mr. W. J. Wilson (Wolverhampton, Assoc. Member, 1943).

Mr. J. W. Graely, Training Officer to the Central Electricity Generating Board, who died suddenly on 23rd March. He was a member of the Education Committee of the Institute and of its School of Welding Technology Sub-Committee. Mr. Graely had taken a special interest in the School and had been a guest speaker at some of the Course dinners.

SCHOOL OF WELDING TECHNOLOGY

The next session of courses commences in October. The first part of the programme is as follows:

Course D1/4—Welded Pressure Vessels (for designers) 2nd–6th October

Course D13/3—Residual Stresses and Stress Relief (for engineers and metallurgists) 16th–17th October

Course D12/3—Practical Control of Distortion (for works engineers and supervisory staff) 18th–20th October.

CO_2 Arc Welding

A recent School of Welding Technology lecture-course on bare-wire CO_2 arc welding is believed to be the first of its type anywhere, and the excellent response from industry to the course is indicative of the current interest in the process and its potential use in engineering production.

In the opening lecture Mr. A. A. Smith dealt with the basic requirements of a gaseous shield, and the special features when using CO_2. The two fundamental types of metal transfer were identified and illustrated by a unique slow-motion film, and the general arc characteristics of the consumable electrode process were described in terms of the several variables. This led naturally into the succeeding lecture on power sources, when Mr. K. G. Lavender discussed the type of source to be selected for CO_2 welding, and described the different units and their control. Mr. D. B. Tait then dealt with the other important aspect of equipment selection, namely, the various methods of wire feeding for both controlled and self-adjusting arc conditions, and types of welding gun. In the subsequent two lectures, the theme changed when Mr. E. J. M. Mitchell and Mr. E. J. Rogers considered the varied metallurgical effects of welding, first without and then with a CO_2 shielding. Factors such as heating and cooling rates, the use of slags, oxidation, the presence of impurities (both in the material to be welded and in the CO_2 shield), and many others were related to weld quality and the soundness of the resultant joint.

A break from the class-room was then provided by the practical demonstrations of CO_2 arc welding equipment, given by four of the leading manufacturers. The demonstrations were held in the Large Hall at the Surbiton Assembly Rooms, to the temporary alarm of the staff, but to the satisfaction of the students, who discussed their own problems with the staff of manufacturers and 'welded' for nearly three hours with the very latest equipment.

After the demonstrations it was fitting that in the following lectures two user companies should describe their own specialised application experience of the process. The warm approval given by the students to the lectures of Mr. L. Jones and Mr. P. Grieve, and the special interest evidenced when cost comparisons were made, suggested that these lectures were the highlight of the course. To the School, however, the pleasure was tinged with a shade of disappointment that so few companies had agreed to contribute to this important part of the course: perhaps more information will be available and forthcoming when the next course is organised. The course concluded with a stimulating survey by Mr. J. A. Lucey of his own ideas of future trends in the development of CO_2 arc welding. The scope of the lecture embraced the use of fluxes and gas mixtures, and led to a final discussion in which both students and a number of the earlier speakers took part.

The course, which lasted for three days, was held at the Institute of Welding and was attended by nearly 50 'students'—supervisors, welding engineers, managers and metallurgists from engineering companies throughout the country. Many applications for places had to be turned down, but so keen was the interest that the School hope to organise a similar course before the end of the year.

The British Oxygen Co. Ltd., Lincoln Electric Co. Ltd., Philips Electrical Ltd., and Rowen-Arc (Division of Robery Owen & Co. Ltd.) were the companies who took part in the demonstrations.

BRANCH NEWS

East Midlands

Fusion Welding Processes

At the February meeting of the Branch Mr. D. B. Tait presented a paper on "*Economic aspects of various fusion welding processes*". He opened his talk by considering first the choice of particular types of manual electrodes for specific applications.

Horizontal-vertical fillet welding

Normal class 2 rutile-type electrodes are usually employed for this position. But it is possible, by using a particular type of rutile electrode with a somewhat heavier covering (and thus about 5% more expensive) to obtain about 10% greater run length from the same length of electrode. Thus, by paying slightly more per thousand feet of electrodes, it is possible to make an overall saving in the cost per thousand feet of deposited weld metal.

This saving can be taken one stage further by using rutile iron-powder electrodes in place of the standard rutile type. The notable decrease in welding time, apart from the saving in electrode costs, makes the extra individual cost of these electrodes well worth while.

Vertical welding

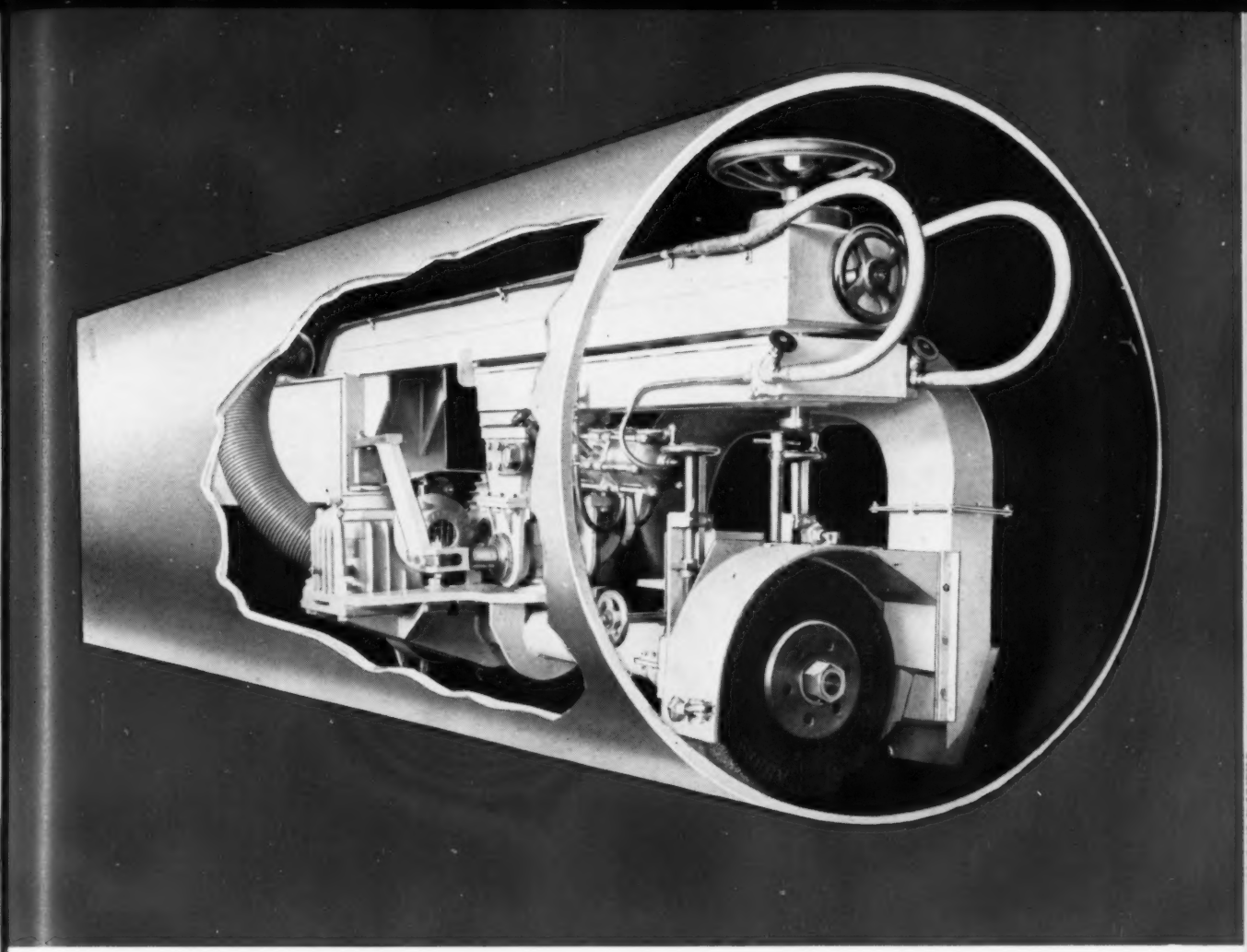
In this position a comparison was made, for butt welds, between normal rutile class 3 electrodes and class 1 electrodes welded vertically downwards. The cost of the cellulose electrode is slightly more than that of class 3 but, because smaller root gaps are needed, the reinforcement is much smaller, and back chipping for full root fusion can be eliminated, the overall cost of using the new technique is considerably less.

Automatic welding processes

A comparison was made between automatic welding and manual welding in terms of depositing 1 lb of weld metal as well as the completion of 1 ft of joint.

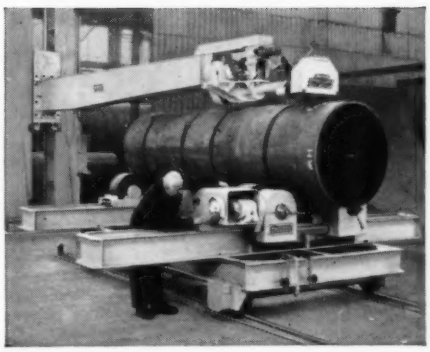
On a weight basis automatic welding does not show to full advantage, for the greater penetration in this process means that less weld metal is in fact used. But on a more rational basis it can readily be shown that the use of automatic welding will give very high savings in welding costs, always assuming that there is sufficient output to utilise the machine to full advantage, and that jigging is provided to allow a high operating factor for the machine.

Several slides were shown to illustrate how proper use of the process could lead to a very high output; for example, the automatic welding of fillets in the shipyard, using a single-headed automatic machine, a twin-headed self-propelled machine, and finally a twin-headed gantry machine. This latter spans the



Automatic Grinding of Welds for X-ray Inspection

The grinding of welds becomes a completely automatic process with the Thompson grinding head. This machine manufactured by Donald Ross & Partners Ltd., speedily removes excess weld overburden and provides a quality finish which is ideal for X-ray inspection purposes. The head will automatically grind both longitudinal and circumferential welds and it is mounted on a column and boom so that it can be used on both the internal and external seams of welded cylinders, boiler shells and pressure vessels, etc. The machine relieves up to four operators of the noisy and arduous task of manual grinding and requires only one semi-skilled workman for its successful operation. The Thompson grinding head is fast, efficient and automatic. It is a modern machine which will save time, labour and money in addition to speeding up production.



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whole working area and so gives high welding speeds and, with the correct shop operation, a duty cycle greater than 75% (*i.e.* arc burning for 6 hr in an 8 hr shift).

In the following discussion a large variety of questions were put to the author, who dealt with them very carefully and capably.

In proposing a vote of thanks, Mr. Seaton thanked Mr. Tait for the excellent paper and the slides that had been shown.

H.S–C.

Liverpool — **Iron powder electrodes**

The lecture to the Branch on 14th February was given by Mr. A. B. Fielding, and was entitled "*Some facts about iron powder electrodes*".

The author commenced by giving a brief history of the development of these electrodes, and cited instances to show that iron powder had been used in electrodes more than 25 years ago.

The reasons for adding iron powder, to improve metal recovery, were outlined and a slide illustrated the faster welding speed obtainable with this type of electrode. Further illustrations also indicated the importance of burn-off rate when calculating electrode efficiency. A series of experiments was described which showed that the addition of iron powder did not necessarily give self-arcing and touch welding properties to the electrodes, and that the maximum amount of powder was governed largely by the welding characteristics required. With excess powder difficulties were encountered with the burn-off of the electrode, and the voltage across the arc was reduced to a level that was undesirable for good welding. Mr. Fielding went on to describe seven different groups of iron-powder electrode, and these were further classified according to the main covering ingredients and iron-powder content, and were related to the appropriate classes in BS.1719.

The effects of rapid cooling and welding current on the ductility of weld metal deposited from iron-powder electrodes were discussed, and a slide was shown to indicate the effect of rapid cooling on the tendency of weld metal to fissuring. The better properties of hydrogen-controlled electrodes, under conditions of rapid cooling, were illustrated by a test specifically designed to induce hydrogen embrittlement in the weld. With this test, basic low-hydrogen electrodes and hydrogen-controlled electrodes showed no tendency to fissure, whereas ordinary rutile iron-powder electrodes were very prone to the fault.

Several tests were described to indicate that low-temperature ageing of weld metals raised the ductility of metal deposited from electrodes that were not hydrogen-controlled, but this improvement was obtained only where fissuring had not been induced by a fast cooling rate. It was shown that heavily covered rutile electrodes of the iron-powder type could be used at very high currents without the weld metal ductility being impaired, provided that they were hydrogen-controlled.

The last part of the lecture was concerned with the applications of iron-powder electrodes. The versatility of the low-hydrogen rutile type was illustrated by a wide variety of examples covering heavy plate welding, high carbon and higher sulphur steels, and galvanised steel.

The advantageous features of the cellulose iron-powder electrodes were explained, especially for the welding of oil storage tanks. By using this type of electrode tank builders have now eliminated the costly operation of back-chipping with resultant savings. These could not be claimed in the cost of welding, but there were many applications where actual savings could be achieved in spite of the higher initial cost of the electrodes. The greatest savings would appear on those applications that allowed a high operating factor, and particularly where labour and overhead charges were high.

H.R.C.

Manchester — **A.G.M.**

The Annual General Meeting of the Branch was held at the College of Science and Technology on Wednesday, 5th April, 1961.

After the formal business proceedings, during which members saw the new Chairman, Mr. S. Wilde, invested with his badge of office by the retiring Chairman, Mr. E. H. Lee, guests joined in for the showing of three most interesting films: "*The Dounreay Fast Reactor*", "*Refinery at Work*", and "*The Port of Manchester*".

All members and friends were asked to note that lectures at future sessions will be held at the Manchester Literary and Philosophical Society's new Lecture Hall, at 36 George Street, Manchester.

A.C.M.

South Western — **A.G.M.**

The Branch Annual General Meeting was held at Radiant House, Bristol, on Monday, 10th April, 1961.

The Chairman and Secretary presented their reports outlining the activities of the Branch during the 1960–1 session. Mr. K. H. McDowell then followed with his Treasurer's report, from which it was encouraging to note the Branch's current stable financial position.

The retiring Chairman, Mr. T. M. B. Sessions, announced that he was leaving the West Country to take up a new appointment in the Midlands. He warmly thanked all concerned for their support during his term of office. He then relinquished office and handed over the duties of Chairman to Mr. G. R. Thomas.

In a moving ceremony, the new chairman presented the Branch President, Mr. A. J. Francis, with a gold watch inscribed with the words "Presented to

Presentation of a gold watch to Mr. A. J. Francis (right) by the President of the South Western Branch, Mr. G. R. Thomas.

A. J. Francis Esq. by the Institute of Welding South Western Branch Committee 1961". The presentation was made as a token of esteem for many years of devotion to the Institute's interests. In reply, Mr. Francis thanked the Committee and recalled the struggle he had as founder member to form the Branch with 50 members, but was very pleased to note its present-day sound footing.

The retiring Secretary, Mr. G. W. Rigby, who incidentally had done a first-class job in taking the photograph illustrated here, relinquished office, and the duties of Secretary were formally taken over by Mr. E. M. Wilson.

The meeting was concluded by showing an excellent colour film entitled "*Steel Rhythm*" by courtesy of The United Steel Companies Ltd.

E.M.W.

Wolverhampton — **Gas-shielded welding**

It was a very great pleasure for many of the members present at the Branch meeting on 15th March to meet Mr. A. A. Smith once again and to hear such a very interesting talk on "*The prospect for gas-shielded welding*".

Before opening his paper Mr. Smith told his audience that this was a very auspicious occasion for him, for it was in Wolverhampton that he struck his first arc, eight years ago, and that it was a great pleasure to be back among so many friends.

Mr. Smith described the prospect for gas-shielded welding as very good, but before looking at the advances made with the process, a look in the past was needed to see what strides have been made. Such dates that come to mind are 1802 when Humphrey Davy made the first arc; 1890, Slavinov produced coatings; 1938 saw the advent of automatic welding using a shroud of flux; and finally emerged the submerged-arc process.

In 1942, in the U.S.A., and in 1945, in Great Britain, the inert-gas process was developed for magnesium using argon, and in 1948 the metal-arc shielded process was initiated.

Mr. Smith felt these dates were the major break-through in this field in approx. 50 years. On the question of gas-shielded welding with only 10 years of technology behind it, the major break-through has been quite fantastic.

Most of these processes are well known, but certain of them warrant discussion: Tungsten-arc welding is used for welding of magnesium and aluminium, and from this introduction came h.f. on a.c. power supply for re-ignition; surge injection; pilot arcs for automatic set-ups; and by far the most important, the constricted arc, whereby by constriction of the arc, and so forming a very narrow path, this could be used as a cutting process or also as a plating process tool, and it was this plasma jet or constricted arc which played such an important role in gas-shielded welding.

Mr. Smith then went on to say that in the consumable electrode processes on aluminium, the constant potential power source gave much improved adjustment.

He then went on to show, with the use of slides, the problem encountered when using high currents. Again the plasma jet was evident and gave rise to puckering and blowing in the weld pool.

Again with the use of slides, Mr. Smith showed his audience the effect of transfer of droplets per second using various combinations of shrouding gases and wires. From this it could be seen that with steel and CO_2 very low transfer was achieved, and by further reducing the voltage by short circuiting an arc was given which is now known as the dip-transfer technique.

Further slides showed the effect on the current using a choke in series, so giving an inductance to the circuit.

Concerning the future, the audience were shown, by the use of more slides, a series of automatic set-ups dealing with different components welded with the process. Fins were shown being welded by tungsten-arc spot welding, the whole operation being controlled from a-tape. Another set-up was the welding of a motor chassis in the three o'clock position giving self locating and positioning of the welding head through the medium of a probe.

In conclusion, a high-speed film was shown of the behaviour of the arc using various conditions of control through current–voltage ranges, with or without induction, and one could clearly see what effect this had on the weld pool and ultimately on the finished weld.

In opening the discussion, Mr. Tait put a series of questions to Mr. Smith. One of interest to many members present was "How are we to choose which process? Elaborating further, if the use of $\frac{1}{4}$ in., $\frac{3}{8}$ in., $\frac{1}{2}$ in. plate is required, do we choose the bare wire process or stick to the conventional type of process?" Mr. Tait asked the same question in relation to positional welding.

In reply, Mr. Smith was of the opinion that where heavier plate was used the process is developed such that economic advantages would be gained especially in the gravity position. For all-positional work, he was of the opinion that the barewire CO_2 process was the easiest to use, and would give economic savings in overall times, speeds, etc.

Further questions were asked by a very appreciative audience, such as the hydrogen content of the filler wire and weld deposit, the effect of welding using this process at site and many others which were dealt with ably by Mr. Smith.

In proposing a vote of thanks Mr. L. Morgan thanked the speaker for dealing with such a fascinating subject in such an able way, and hoped that it would not be very long before Mr. Smith would be with them again at Wolverhampton, to give them further news on the development which must surely come with this process. Mr. Baker seconded the vote of thanks.

J.W.G.

OTHER SOCIETIES

Irish Welding Association

The Management Committee of the Association for the session 1961–2, has been elected as follows:

Chairman: Mr. W. Dresser (Arthur Guiness Son & Co. (Dublin) Ltd.)

Hon. Secretary: Mr. W. Cronin (Electricity Supply Board)

Hon. Treasurer: Mr. S. Warnock Aitkin (Industrial Gases (I.F.S.) Ltd.)

Members:
Mr. S. J. McGloughlin (J. & C. McGloughlin Ltd.)
Mr. T. W. Bamford (Universal Fabricators Ltd.)
Mr. B. G. Cantwell (Unidare Ltd.)
Mr. J. C. Costello, B.Sc.
Mr. J. D. Barry (College of Technology, Dublin)
Mr. P. Donegan (National Engineering Union)
Mr. H. Munroe (Varming & Mulcahy).

Institution of Metallurgists

At the Annual Luncheon of the Institution of Metallurgists, at the Park Lane Hotel, on 17th May, the President, Dr. N. P. Allen, announced the successful conclusion of the movement for the closer co-operation of the Institution with the Institute of Metals and the Iron and Steel Institute.

Dr. Allen was in the chair and responded to the toast of "The Institution", which was proposed by Sir Patrick Linstead, O.B.E., F.R.S. The toast of "The Guests" was proposed by Dr. E. G. West, and the reply was made by Sir William Cook, C.B.

Co-operation between Metallurgical Societies

The Councils of the Iron and Steel Institute, the Institute of Metals and the Institution of Metallurgists have recently examined the problems of closer co-operation between the three societies. After careful consideration they have concluded that amalgamation would not be practicable within the foreseeable future. The three Councils therefore decided to set up a permanent Joint Consultative Committee of the

three societies which will meet regularly and advise their Councils on all activities and questions of common interest.

The three Councils are convinced that every qualified metallurgist should be a Member both of the professional institution and of his appropriate scientific and technical institute, and should contribute to and influence the work of both. With this in view, the Council of The Institution of Metallurgists has altered the Standard Subscriptions payable by Members, Enrolled Graduates, and Enrolled Students of the Institution resident in the United Kingdom; by agreement of the three Councils all those in The Institution of Metallurgists who pay these revised Standard Subscriptions will automatically have the right to apply for Membership of one of the two Institutes without liability for the payment of a further Membership subscription to that Institute.

Full details are contained in *The Metallurgist*, vol. 1, No. 8, March 1961, published by The Institution of Metallurgists.

NEWS FROM INDUSTRY

Computer controlled cutting

The second 'Eagle' computer-controlled gas cutting machine (see *BWJ*, Feb. 1961, p.72) has successfully completed its acceptance trials at the Edmonton Works of The British Oxygen Co. Ltd., and will now be installed at the Barrow Yard of Vickers-Armstrong (Shipbuilders) Ltd. for commissioning trials.

The machine is a double-headed precision profiling cutter with all operations controlled from a programmed magnetic tape. It can cut simultaneously two plates each up to 40 ft long, 12 ft wide, and 3 in. thick.

Press collaboration

A new jointly owned British Company, Schuler Presses Ltd., has been formed by Wickman Ltd., Coventry, and L. Schuler A.G., Goeppingen, Germany.

Its object is to establish the manufacture of certain Schuler presses in the U.K. and to provide a British-based engineering and after-sales service to all Schuler press users.

Wickman Ltd. will act as exclusive sales representatives for the range of Schuler presses.

BEAMA Presentation

At a recent luncheon of the BEAMA Arc Welding Electrode Section, Mr. W. W. Watt, C.B.E., was presented with a Persian carpet to mark his service to the industry, particularly as the Chairman of the Section since its formation in 1939. The luncheon was presided over by Mr. L. A. Lidstone, who took over the Chairmanship of the Section from Mr. Watt in 1960, and guests included Sir Charles Lillicrap, K.C.B., M.B.E., President of BWRA, Sir Leslie Robinson, K.B.E., C.B., of the Board of Trade, and Mr. J. Turnbull, C.B.E., of Lloyd's Register of Shipping.

Mr. Watt who was Managing Director of BOC from 1937 to 1956, was President of the Institute of Welding in 1941, and in the following year was appointed President of the British Acetylene Association.

"O for Oxygen"

To mark the occasion of the 75th anniversary of The British Oxygen Company Ltd. a film has been made to show the development and wide applications of oxygen.

The film, in colour, and made by World Wide Pictures Ltd., runs for 23 minutes, and contains many interesting examples of the use of oxygen and other atmospheric gases in welding.

Branch Secretaries will be interested to learn that copies of the film in 16 mm and 35 mm will soon be available on free loan from BOC to schools, colleges and similar organisations.

Industrial Finishes

At one of the technical sessions of the Industrial Finishes Convention, held at Earl's Court in May in conjunction with the first Industrial Finishes Exhibition, two papers on metal spraying were presented under the Chairmanship of Mr. H. W. Fender, of the Metal and Plastic Coatings Association.

They were: "*Metal spraying for finishing preparatory treatments*", by J. F. Stanners (BISRA); and "*Painting of sprayed metal coatings*", by Dr. L. Valentine (Paint Research Station).

Magnetic crack detection inks

A new range of inks and powders for magnetic crack detection has been produced by Southern Tools Ltd., Cheam, Surrey. Black/grey high sensitivity ink contrasts well on both bright and black surfaces. A fluorescent ink gives a clear bright glow in u.v. light.

The range includes three powders: black, grey, and copper red.

Intermittent spot welding

Where spot welds are pitched at intervals along sheet seams it is usual for the operator to judge the correct intervals and to move the sheets manually in a normal spot welder.

To increase the speed of production and to provide more accurate spacing for this type of work Siemens-Schuckert (Gt. Britain) Ltd. have evolved a technique for adapting their seam welding machines to do this work.

The machine electrode wheels are rotated intermittently, the variable-speed-ratio gearbox normally fitted being adjusted to a high rate to give fast movement of the material between spot welds. An electro-magnetic clutch is interposed between this motor and the wheel, declutched when the weld is required and re-engaged to the drive motor to move the material at a fast rate up to the next welding position. A timer is incorporated to give a delay between the de-energising of the clutch and the weld to ensure that the wheels stop during the welding operation. On two 16 s.w.g. mild steel sheets the effective overall speed with 2 in. spacing was approximately 18 ft/min. whilst with 3 in. spacing an effective speed of over 22 ft/min was obtained. On a production job, in a spot welder, with pitching at 6 in. controlled manually, the speed was only 12 ft/min.

This system of operation is the subject of a Patent Application.

Liquid gas plant

A new plant for producing liquid hydrogen and liquid helium is now in service at the British Oxygen Scientific Division, Morden, Surrey. It will help the Division to meet the rising demand from industry and research bodies for these liquefied gases.

The first plants in the U.K. for producing liquid hydrogen and liquid helium on a commercial basis began operating at Morden during last year.

STUB ENDS

▶The offices of the Midland Branch of Teleflex Products Ltd. are now at Lichfields House, Ringway Centre, Birmingham. The Teleflex Group have recently incorporated the Conveyor Construction & Engineering Co. Ltd. of Eastbourne.

▶Weldcraft Ltd., Slough, have appointed Hilarius, Draadindustrie en Handelmaatschappy, Haarlem, as their Agents in the Netherlands for the Gasfluxer process.

▶Mr. H. T. Jenkins has been appointed Technical Director, and Mr. J. S. Waring Production Director of Robert Jenkins & Co. Ltd., Rotherham.

▶The Council of the Electrical Research Association has elected Mr. L. Rotherham (Central Electricity Generating Board) as Chairman for 1961–2, and Mr. S. E. Goodall (A.E.I. (Woolwich) Ltd.) as Vice-Chairman.

CORRECTION

Welded Maidenhead Bridge

It has been pointed out that the protective treatment given to the steelwork of this bridge (see *BWJ*, June 1961, p.300) was three coats of white *phenolic* paint.

Current WELDING LITERATURE

Book Reviews
Additions to the Institute Library
Trade Publications

CONTENTS OF PERIODICALS RECEIVED

This section is intended to give a survey of the current welding literature received by the Institute of Welding Library. The contents lists are not exhaustive; only the main articles in welding journals are listed, and reprints from other journals and short notes are generally excluded. In addition, welding articles from other periodicals are listed. Abstracts of welding literature are given in the Bibliographical Bulletin of Welding and Allied Processes, *published by the International Institute of Welding, and details of this may be obtained from the Secretary of the Institute of Welding.*

Welding Journals

Canadian Welder, 1961, vol. 52, March

Oxy-propane brazing with flux injection, S. Smith (10–12)
Pipeline welder training programme, W. L. Daniels (14–17)
Motor-generator sets as power sources for automatic welding, W. F. Auld (18–19)

International Welding, 1961, vol. 1, No. 1, Spring

Reports on fatigue failures (1*s*–16*s*)
Enquiry on fatigue failures, IIW Commission XIII (16*s*)
Reports of Commissions—1960. I–VII (17*s*–28*s*)

La Saldatura Autogena (Milan), 1961, vol. 42, January-February

Welded bridge. Part 1 (4–16)
Welding in the manufacture of machines and particularly of machine tools (20–23)

Journal of the Japan Welding Society, 1961, vol. 30, No. 2

Fundamental studies and industrial practice in cold pressure welding, T. Saito and K. Yamaji (2–11)
A study of cracking in the weld zone of 50 kg/mm² class high tensile steels, S. Ando and S. Mori (25–34)
Welding conditions of CO_2-O_2 arc welding. Report 2. Relationship between welding conditions and deposition efficiency, H. Sekiguchi and I. Masumoto (35–39)
The properties of the oxy-acetylene flame. Report 5. Composition of combustion gas, I. Onishi and others (40–45)
Argon-hydrogen arc cutting, T. Ikkai and F. Watanabe (46–51)
Carbon dioxide shielded metal arc welding with steel electrode containing aluminium, S. Morita and others (52–57)
Research on welding stress. Report 1. The generation process of welding strains, H. Mikashima and S. Mukai (58–62)

Lastechniek (Netherlands), 1961, vol. 27, February

Autogenous welding of aluminium (27–29; 32–33)
Some new welding processes. 2. Welding with the electronic gun, G. van Schaik Zillesen (33–34)
Fabricating milk cans, F. Loos (34–36)

Oerlikon Schweissmitteilungen (Zurich), 1961, vol. 19, No. 41

Solving the safety problems in maintenance welding in atomic energy plant, E. B. Lavelle and R. H. Scott (9–21)

Rivista Italiana della Saldatura, 1961, vol. 13, January-February

Brittle fracture in steel considered from the builder's point of view, U. Guerrera (3–9)
Report on the work of the Technical Commissions of the International Institute of Welding (16–28)

Schweissen und Schneiden (Germany), 1961, vol. 13, April

Tension shear forces obtainable in the spot welding of carbon steel, in sheet thicknesses up to 6 mm, O. Becken and K. Havers (127–135)
Influence values, quality and strength in resistance spot welding, W. Glage (135–139)
Metallurgy of electrodes for arc welding, P. E. Wimmer (140–146)
Projection welding reduces production times, E. A. Otto (146–151)
Progress of welding technique in the U.S.A., K. L. Zeyen (152–159)
Root welding of heavy duty pipes in low and high alloy steels, R. Faulstich (160–165)

Schweisstechnik (Berlin), 1961, vol. 11, March

Building-up by automatic welding of working parts in lignite mining, K. Muller (97–100)
Economical application of oxy-acetylene welding to cast iron repairs, F. Wuttke (100–106)
Hard-facing by thermit welding of parts subjected to abrasion, W. Novak (106–108)
Large scale repair welding in the reconstruction of the Pumpspeicherwerk Hohenwarte I, W. Fritzsche (109–118)
Hard facing of tools, R. Walther (118–121)
Incorrect execution of a pressure vessel assembly causes repairing, A. Bock (122–126)
Building-up of rails by submerged-arc welding with alloying flux, A. Missikewitsch (127–130)
The production of pipes for the oil pipeline USSR-PR Poland in the VEB Rohrleitungsbau Bitterfeld, R. Kind and others (132–134)

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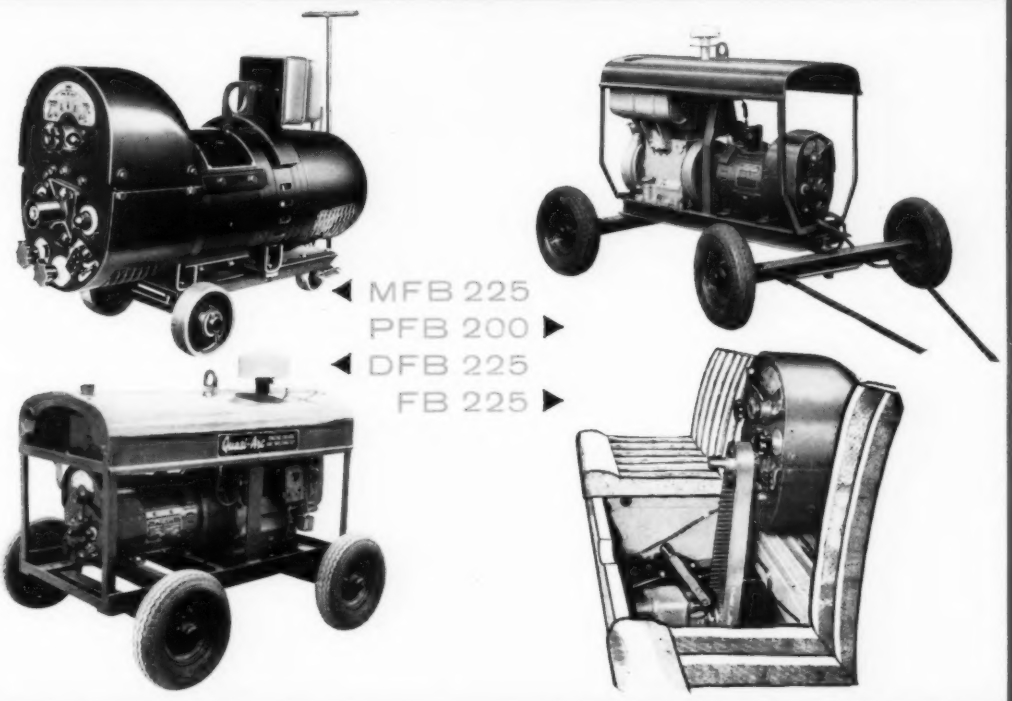

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Schweisstechnik (Vienna), 1961, vol. 15, April

Three phase plant for resistance welding, H. U. Neidhardt (37–43)

Submerged arc welding of large diameter piping, Dr. Mennen (43–46)

Effect of higher frequencies in arc welding (46)

Sveiseteknikk (Oslo), 1961, vol. 16, March

Metallizing guns and their applications, S. B. Giersten (1–7)

Welding of corrosion-resisting steel pipe, R. H. Sovik (8–10)

Welding Design and Fabrication (U.S.A.), 1960, vol. 33, August

Welded highway bridges . . . are the figures as good as they look? (23–26)

Blanket braze dished honeycomb panels (29)

Need 400 welding arcs? Use only 10 power sources, H. Lefer (30–31)

The impact of cryogenics on the welding industry (36–37)

Structural welding is 17 percent cheaper than bolting (44–46)

Welding Design and Fabrication (U.S.A.), 1960, vol. 33, September

Will aluminium replace steel in welded freight cars? (36–38)

Automatic brazing for uniformity and production, C. S. Whitaker (39)

Techniques for fabricating and welding the Titan missile (42–43)

How to weld boron stainless steel without cracks or distortion, J. Potochnik (44–45)

Design special columns and girders for welded skyscraper, P. Drier (46–47)

Arc gouging stainless steel welds cuts rework time 93 percent (52–55)

The metal fabricating processes. Part I. Shearing and forming (57–65)

Welding Design and Fabrication (U.S.A.), 1960, vol. 33, October

The newest ways to cut and join magnesium, T. L. Patton (39, 41)

Techniques for fabricating and welding clad steels thicker than 2 inches, A. Hoersch (42–43; 74)

Five ways you can improve the quality of your spot welding (44–45; 74)

Heat exchanger tube welds are radiographically sound (46–47)

What we now know about electron beam welding, D. N. Reece (52–53; 76)

The metal fabricating processes. Part 2. Mechanical cutting; arc and flame cutting and gouging; pipe cutting and beveling (57–72)

Welding Design and Fabrication (U.S.A.), 1960, vol. 33, November

Does a radiographed vessel cost more to build than one that isn't? R. Chuse (31–32)

Spot welding is the key to reliable miniaturized electronic parts (34–35; 51)

Leak-free welds are the key to world's largest stainless steel spheres (38–39; 40)

Sea will see more aluminium boats (43)

How to make welding hose and cable last longer (44–45)

Why have fabricated turbine runners replaced one-piece castings? C. R. Frounfelker (48; 50)

Why Martin brazes in a vacuum furnace, M. Schwartz (52; 54)

Welding Design and Fabrication (U.S.A.), 1960, vol. 33, December

Positioning/Handling ideas (33–36)

Cut dished stainless steel heads with the tungsten arc process (40–41)

How Republic Steel rates nondestructive tests, W. A. Black (42–44)

How to design a welded roll (47–49)

Metallizing protects conduit, boosts sales (50, 54)

Why stress relieve cryogenic vessels made from 9% nickel steels? (57–59)

Automatic line combines resistance welding with forming and piercing, T. C. Falter (62–64)

Welding Design and Fabrication (U.S.A.), 1961, vol. 34, January

Do welding users want price or performance in 1961 (31–33)

Weld metal has excellent properties! Are you using them? (34–35)

How to weld the cobalt alloys, W. J. Lepkowski and R. E. Monroe (37, 39)

Techniques for fabricating and welding aluminium tank cars, J. F. O'Connell (52–55)

Techniques for faster, cheaper welding of heavy aluminium plate (56–57)

Punched tape whisks 27,000 spotwelds into position (58–59)

Filler wire is key to new CO_2 spray arc welding process, C. R. Sibley (60; 62–63)

Four methods for brazing B-70 stainless honeycombs (64–65)

Welding Design and Fabrication (U.S.A.), 1961, vol. 34, February

Automatic welding: better tanks with half the work, J. Devoldre (50–51)

Welded aluminium suits sonar (55–56)

Best bet for silver brazing: a narrow gap (60, 62)

Will explosive welding be the newest metal joining process? (63)

New semi-automatic arc welding process speeds mild steel fabrication (64–65)

Welding Design and Fabrication (U.S.A.), 1961, vol. 34 March

Automatic drilling and welding speed bridge fabrication (30–31)

Guide to major welding specifications and codes (36–38)

Graphite cloth speeds honeycomb brazing (40; 48)

We can predict spot weld strength, W. A. Soward (45–46)

Ultrasonic testing (54–55)

Radiographic inspection (56–61)

Penetrant inspection (62)

Magnetic particle inspection (66)

Welding Engineer (U.S.A.), 1961, vol. 46, March

Fabrication of nuclear piping demands revised welding procedures, R. H. Hoefler (25–26)

Fiber metallurgy promises greater efficiency in resistance welding, H. Schwartzbart (27–29)

Steel island is $30 million sulphur mine, T. Anderson and E. L. Trimble (30–31)

Navy welding school takes its first steps into the nuclear age, J. Hurlburt (32–33)

Proper welding saves thousands of dollars for the Ford Motor Co., F. T. Tancula (34–36)

Production line practices speed heavy equipment fabrication (38–40)

Welding Engineer (U.S.A.), 1961, vol. 46, April

Tests prove 9% nickel steel meets requirements for cryogenic service (46–47)

Thin-metals percussive welded without marring or distortion, C. A. Gunn (48–49)

How to evaluate shrink and draw stains, N. S. Hodska (50–52)

Welding aids plastic industry, A. W. Anderson and M. J. Quigley (58)

Reactive metal tubing is Tig welded on a production basis (60, 62)

Welding HY-80. Survey of notch tough steels shows fabrication problems, T. J. Dawson (75–76, 78)

Welded saw blade joints must meet rigid specifications, F. B. Jacob (80, 82)

Nickel-silver brazing solves stapling machine production problems, J. Poulson (88, 90)

Welding Fabrication and Design (Australia), 1961, vol 4, March

Some recent developments in shipbuilding overseas. Paper I, R. Hawke (5–7)

Some recent developments in shipbuilding overseas. Paper II, I. Butler (8–12)

Roll wobbler reconditioning (17–18)

Other Journals

Model methods, with particular reference to three recent applications in the fields of steel, composite and concrete construction, S. R. Sparkes and J. C. Chapman (*Structural Engineer*, 1961, vol. 39, March, pp. 85–99)

Aluminium for heat protective armour, C. H. Neukirchen (*Light Metals*, 1961, vol. 24, March, pp. 68–69)

Reactor gets repair-free welds. Aluminium-magnesium alloy meets weldability needs (*Iron Age* (U.S.A.), 1961, vol. 187, February 16, pp. 106–107)

The mechanism of stress corrosion in a high-purity aluminium-zinc-magnesium alloy, E. N. Pugh and W. R. D. Jones (*Metallurgia*, 1961, vol. 63, January, pp. 3–6)

Physical properties and constitution of liquid slags, B. T. Bradbury and D. J. Williams (*Metallurgia*, 1961, vol. 63, January, pp. 19–24)

High tensile steel girders for Melbourne Bridge (*Australian Mechanical Engineering*, 1961, vol. 48, January 5, pp. 23–26)

Ryan dotwelds through thick and thin (*Steel* (U.S.A.), 1961, vol. 148, February 27, p. 126)

Engineers come to grips with weld distortion (*Iron Age* (U.S.A.) 1961, vol. 187, February 23, pp. 104–106)

Planning for nondestructive testing by use of radiation, F. S. Sutherland (*Machine Production* (Canada), 1961, vol. 20, February, pp. 26–29)

Aluminium and its alloys in 1960. Some aspects of research and technical progress reported, E. Elliott (*Metallurgia*, 1961, vol. 63, February, pp. 65–70)

Armoured conveyor production at Butterley (*Iron and Steel*, 1961, vol. 34, April, pp. 147–148)

Selecting a power source for arc welding, J. E. Hinkel (*Machinery Lloyd*, 1961, vol. 33, March 25, pp. 21–22)

Resistance butt-welding of steel wires, particularly of wires having a high content of carbon, H. J. Bockenhoff (*Stahl und Eisen* (Germany), 1961, vol. 81, March 16, pp. 337–349)

Industrial noise hazards and their prevention, D. E. Hickish (*Journal of the Institution of Electrical Engineers*, 1961, vol. 7, March, pp. 151–155)

Electroslag welding (*Maskin Industrien* (Denmark), 1961, vol. 12, February 28, pp. 140–143)

Silicon in steel (*Mechanical World*, 1961, vol. 141, February, pp. 53–54)

Continuous cooling transformation diagrams of steels for welding and their applications, M. Inagaki and H. Sekiguchi (*Transactions of the National Research Institute for Metals* (Japan), 1960, vol. 2, No. 2, pp. 102–125)

Electroslag welding. Part 2 (*Maskin Industrien* (Denmark), 1961, vol. 12, March 15, pp. 191–192)

An introduction to the problems of metal fatigue, G. M. Astles (*Engineering Materials and Design*, 1961, vol. 4, April, pp. 212–216)

Testing honeycomb for fatigue (*Engineering Materials and Design*, 1961, vol. 4, April, p. 239)

A simple test for open face honeycomb (*Steel* (U.S.A.), 1961, vol. 148, March 13, pp. 132)

Electron beam weld shows light touch (*Steel* (U.S.A.), 1961, vol. 148, March 13, p. 135)

Rotating unit welds pipeline (*Iron Age* (U.S.A.), 1961, vol. 187, March 9, p. 95)

Chemical machining (*Aircraft Production*, 1961, vol 23, April, pp. 138–141)

Precision orbital welding (*Aircraft Production*, 1961, vol. 23, April, p. 141)

The silicon controlled rectifier, A. J. Sadler and P. A. Turner (*A.E.I. Engineering*, 1961, vol. 1, March, pp. 124–130)

Fatigue strength of marine shafting, G. P. Smedley and B. K. Batten (*Transactions of the North East Coast Institution of Engineers and Shipbuilders*, 1961, vol. 77, March, pp. 293–301)

The world's longest submarine aquaduct, ingenious methods and equipment used for making and laying a 14½ mile undersea pipeline (*Pipes and Pipelines*, 1961, vol. 6, March, pp. 45–48)

Plastic pipe (*Pipes and Pipelines*, 1961, vol. 6, March, pp. 49–52)

Developments in the use of plastic drainage pipe in the Netherlands (*Pipes and Pipelines*, 1961, vol. 6, March, pp. 53–55)

Survey of present day ultrasonic equipment, C. A. Meadows (*British Journal of Non-Destructive Testing*, 1961, vol. 3, March, pp. 2–10)

The inspection of pressure components intended for nuclear service, J. A. Frew (*British Journal of Non-Destructive Test ing*, 1961, vol. 3, March, pp. 10–13)

Some non-destructive methods of determining the properties of materials and structures, A. E. Cawkell (*British Journal of Non-Destructive Testing*, 1961, vol. 3, March, pp. 14–26)

The trends in ultrasonic development, J. Krautkramer (*British Journal of Non-Destructive Testing*, 1961, vol. 3, March, pp. 26–32)

Some problems in shipbreaking, M. Wilkinson (*Transactions of the Institution of Engineers and Shipbuilders in Scotland*, 1961, vol. 104, Part 4, pp. 187–204)

Properties and theory of the electric arc. A review of progress, H. Edels (*Proceedings of the Institution of Electrical Engineers, Part A. Power Engineering*, 1961, vol. 108, February, pp. 55–69)

Recent research on fatigue in metals, P. G. Forrest (*Chartered Mechanical Engineer*, 1961, vol. 8, March, pp. 148–157)

Up-to-date argon arc welding plant and its applications, C. Holmstrom (*Aga Svetsning* (Sweden), 1961, No. 1, pp. 1–5)

Building-up by hardfacing, Part 2 (*Aga Svetsning* (Sweden), 1961, No. 1, pp. 7–12)

Welded surface plates, A. H. Kleinsorge (*Mechanical Engineering* (U.S.A.), 1961, vol. 83, March, pp. 52–54)

Welding of thermoplastics (*Engineering Materials and Design*, 1961, vol. 4, March, p. 155)

Welding meets challenge of space age metals, R. R. Irving (*Iron Age* (U.S.A.), 1961, vol. 187, April 6, pp. 99–106)

Beryllium bolts gain strength (*Iron Age* (U.S.A.), 1961, vol. 187, April 6, p. 107)

Can uranium improve steel? S. L. Gertsman (*Iron Age* (U.S.A.), 1961, vol. 187, April 6, pp. 110–111)

Immersion tests reduce waste (*Iron Age* (U.S.A.), 1961, vol. 187, April 6, p. 112)

Welding in nuclear engineering (*Nuclear Engineering*, 1961, vol. 6, May, p. 177)

Tube-to-tube plate connections, S. E. Gallant (*Nuclear Engineering*, 1961, vol. 6, May, pp. 187–188)

Welding stainless steels, M. C. T. Bystram (*Nuclear Engineering*, 1961, vol. 6, May, pp. 193–198)

BOOKS AND PAMPHLETS

CLARK, JAMES G. *Welded interstate highway bridges.* Cleveland, Ohio, James F. Lincoln Arc Welding Foundation, 1960. (Price $2.50)

CARLIN, BENSON. *Ultrasonics.* 2nd ed. London, McGraw-Hill Book Company Inc., 1960. Price £4 10*s*.)

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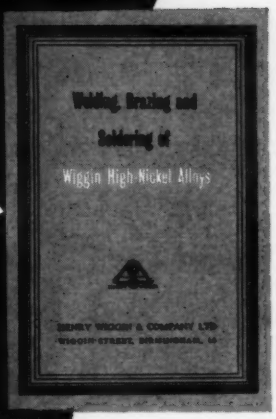

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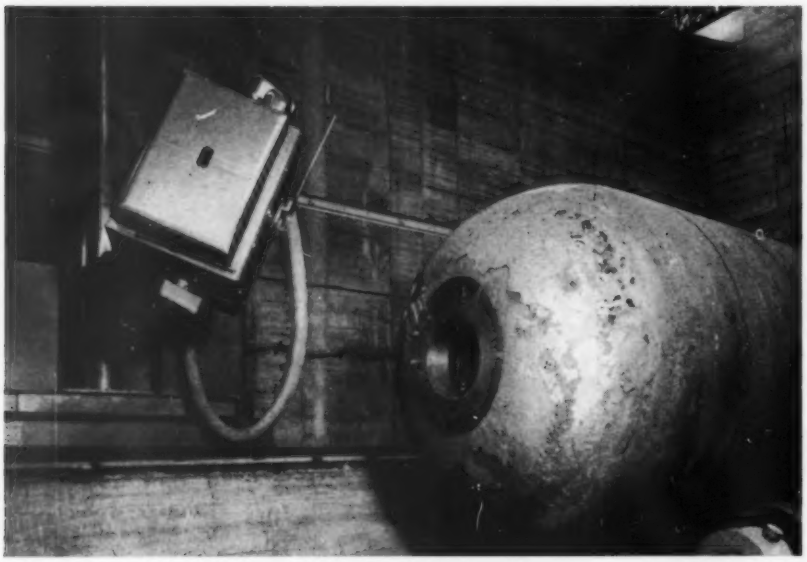

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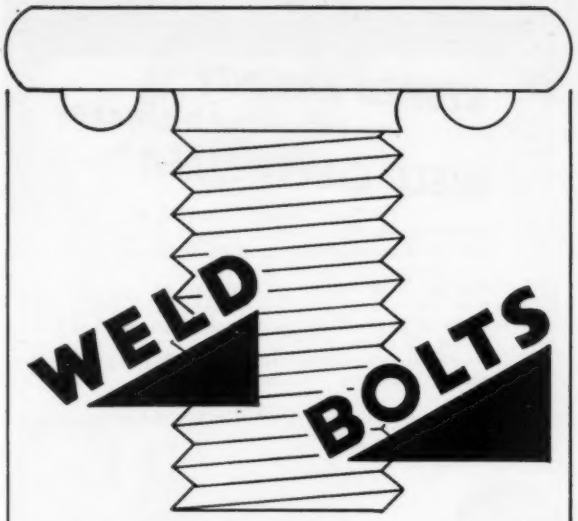

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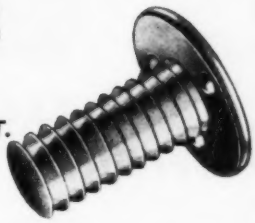

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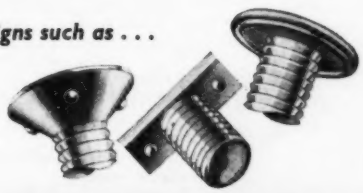

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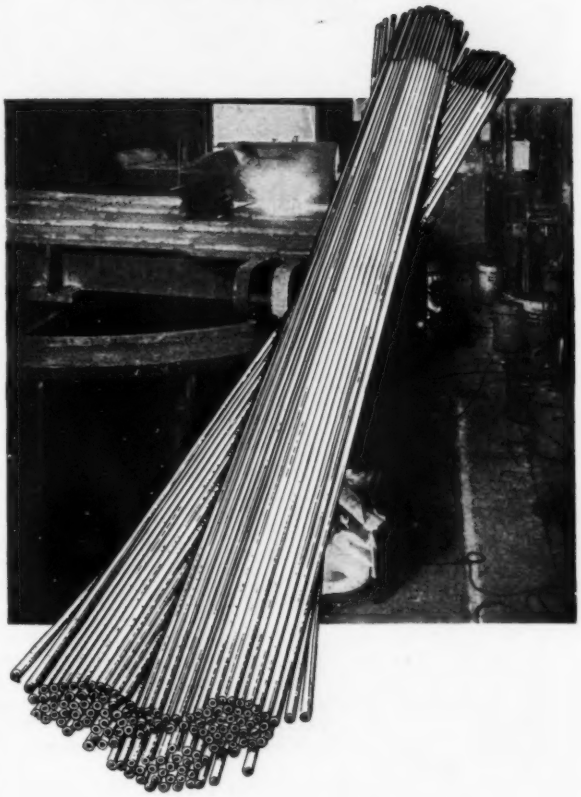

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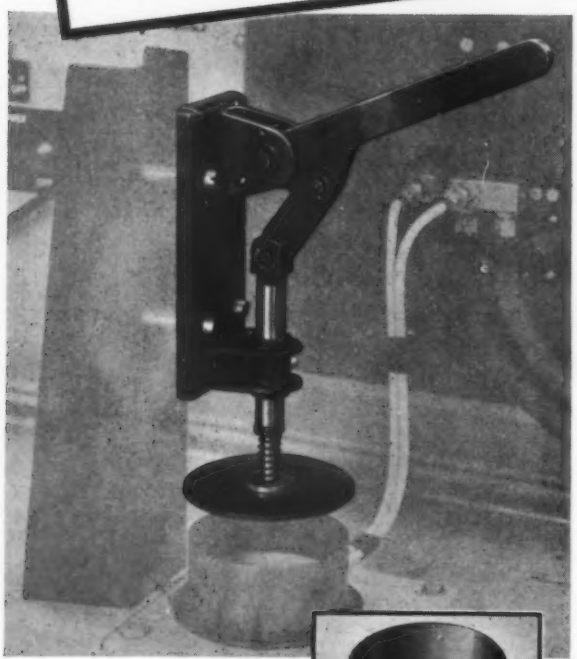

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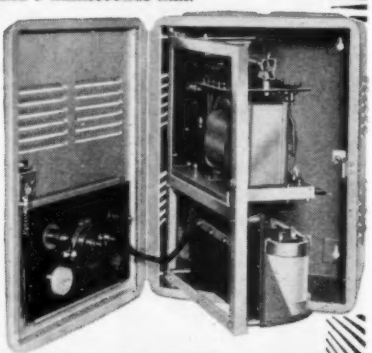

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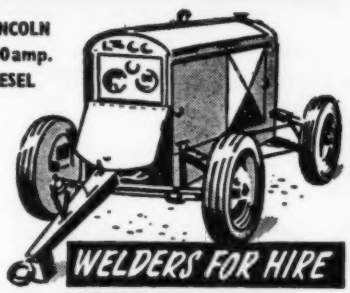

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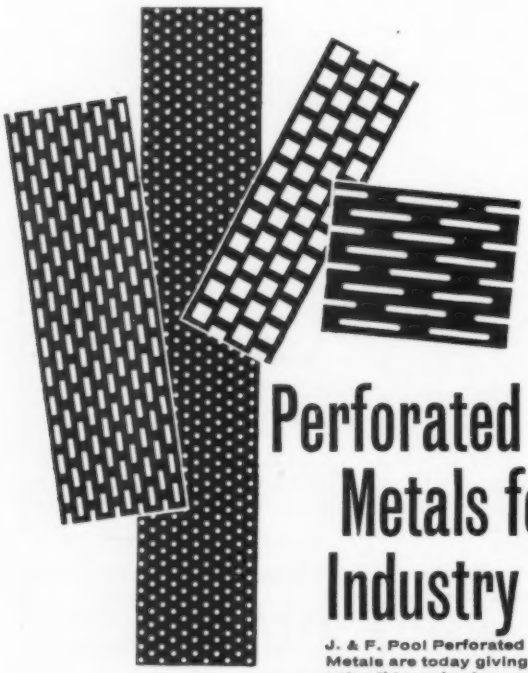

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